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SOIL STUDIES OF BROWN ROOT ROT OF TOBACCO

I. Effect of Certain Crop Residues on Some Forms of Nitrogen[1]

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INTRODUCTION

Brown root rot of tobacco is a disease that is widely prevalent in the tobacco-growing districts of eastern Canada and the United States. A number of papers have been published within the last ten or fifteen years dealing with various aspects of the trouble, but as yet the fundamental cause of the disease is unknown.

Johnson (6) in 1924, pointed out that brown root rot is distinct from black root rot of tobacco, the latter being due to the fungus *Thielavia basicola*. Brown root rot can be controlled by sterilization of soils with either heat or formaldehyde, but the casual agent persists in the soil from year to year, though it may die out under excessive drying or absence of the host plant. The cause may have some connection with other crops as the disease is common on sod land the first year planted with tobacco. Relatively cool weather seems to favour the disease. Drying or aeration of the soil is favourable to recovery.

In Kentucky (10), the disease was found to be quite severe following a crop of corn, chiefly on fields of low available fertility. Though several organisms were isolated from rotten roots, it could not be shown that any particular one was the cause of the trouble. Dead corn roots from a continuous corn plot, introduced into sand cultures, caused a similar disease in tobacco.

In 1926, it was reported from Connecticut (1) that no specific organism was found associated with brown root rot of tobacco. Sterilization with steam and formaldehyde prevented the disease, thus suggesting it was caused by an organism. On the other hand, aerating the soil in a thin layer for two weeks also prevented the disease, and no known pathogen can be destroyed by such mild treatment. The disease seemed to be associated with preceding crops and cover crops, *e.g.* timothy, though many fields cropped alike for several years showed the disease only in patches. The soil reaction had no influence and the application of additional fertilizers did not help.

Johnson, Slagg and Murwin (7) found evidence which led them to believe that the cause of this disease might be either parasitic or non-

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parasitic. The physical condition and acid-reaction of the soil were not responsible. Soil temperature was important but soil moisture was not very important, though dry weather favoured the disease. A large part of the injurious agent seemed to exist in the organic matter.

Doran (4) working with timothy infusions, was able to induce a disease similar to the brown root rot. He found the toxicity of the infusions varied with age and thought that perhaps toxins were formed in the decomposition of the organic material.

Thomas (9) believed that the trouble was due to lack of nitrates in the early spring, cellulose decomposers using up all available nitrogen and leaving none for the tobacco plants which need an abundance in the early stages of growth. No brown root rot resulted when applications of 3,000 lbs. $(NH_4)_2\ SO_4$ and 6,000 lbs. superphosphate per acre were made.

Eisenmenger (5) worked on the theory that aluminum poisoning was responsible. He found no evidence either that crops such as corn and timothy released aluminum, or that toxicity with excess aluminum produced the symptoms of the brown root rot disease.

Beaumont (3) put forward a hypothesis to explain the disease, based on his observations over a period of years. He suggested that the unoxidized forms of nitrogen, resulting from the decomposition of plant residues, are responsible for the occurrence of brown root rot, not because these forms of nitrogen are directly toxic to the plant, but because they set up conditions in the roots which permit them to be readily attacked by common decay organisms.

EXPERIMENTAL METHODS

In starting an investigation into the causes of brown root rot of tobacco in this laboratory, it was decided to study the occurrence of some of the forms of nitrogen in the soil, and how the amounts of these were affected by additions of the residues, *i.e.* roots and stubble, of certain crops. Three series of experiments were run. In the first, a light sandy soil from the experimental plots of the Division of Chemistry, Central Experimental Farm, Ottawa, was used. The samples collected were air-dried and screened through a 2 mm. screen. Samples of the stubble of timothy, corn, alfalfa and oats were also collected, air-dried and coarsely ground in a Wiley mill.

Samples of about $1\frac{1}{4}$ kg. of soil were remoistened to about 60% of their water holding capacity, treated as shown below, kept in the laboratory in large, loosely-stoppered glass bottles, and portions withdrawn at intervals for analysis.

The treatments used were as follows:—

1. Soil from corn plot—nothing added.
2. Soil from corn plot—about 1.5% ground corn stubble.
3. Soil from corn plot—$MgCO_3$ at the rate of approximately 1,000 lb. per acre.
4. Soil from corn plot—both $MgCO_3$ and corn stubble, as above.
5. Soil from corn plot—$CaCO_3$ at the rate of approximately 2 tons per acre.

6. Soil from corn plot—both $CaCO_3$ and corn stubble as above.
7. Soil from timothy plot—nothing added.
8. Soil from timothy plot—about 1.5% ground timothy stubble.
9. Soil from timothy plot—$MgCO_3$ at the rate of approximately 1,000 lb. per acre.
10. Soil from timothy plot—both $MgCO_3$ and timothy stubble as above.
11. Soil from timothy plot—about 1.5% ground corn stubble.
12. Soil from alfalfa plot—nothing added.
13. Soil from alfalfa plot—about 1.5% ground alfalfa stubble.

Methods of Analysis

Results are presented showing the amount of ammonia, nitrite, and nitrate-nitrogen in these samples at intervals of several weeks after treatment. In determining the ammonia, the soil was extracted with 10% NaCl solution, filtered, and the filtrate distilled from excess MgO, the ammonia being collected in standard 0.02N H_2SO_4. This is essentially the method of McLean and Robinson (8).

For the determination of nitrites and nitrates, the extracting solution used was distilled water containing 1.2 g. aluminium sulphate as recommended by Bartholemew (2) for nitrites. Calcium hydroxide was used to clarify the solution after shaking. Nitrites were determined colorimetrically, using sulphanilic acid and alphanaphthylamine to develop the colour. Nitrates were determined by the phenoldisulphonic acid method.

RESULTS

First Series

Tables 1, 2, and 3 show the results obtained for ammonia, nitrites and nitrates respectively with the first series. It will be seen that in the great majority of cases, the ammonia content is below 5 p.p.m. The only cases where there is any considerable accumulation of ammonia is in Sample 13, soil treated with alfalfa stubble, after 2, 6 and 10 weeks. In

TABLE 1.—AMMONIACAL NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	12.6	—	3.4	2.2	1.8
2	8.7	2.7	3.7	1.0	2.8
3	6.9	0	1.7	0.5	1.9
4	2.4	1.2	1.7	0.5	0.9
5	3.5	0	2.5	0.5	1.4
6	3.5	2.0	3.0	0.5	1.4
7	4.6	4.5	3.2	0.5	3.1
8	3.7	2.9	3.2	0	2.6
9	4.6	3.3	1.8	0.5	2.1
10	0.8	3.7	6.8	0	2.0
11	3.7	7.7	6.2	0.5	1.5
12	0.8	3.5	2.5	0	2.4
13	88.8	58.9	62.6	6.3	6.8

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TABLE 2.—NITRITE-NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven-dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	0.7	0.3	0.5	0.2	0.2
2	0.3	0.3	0.5	0.2	0.3
3	0.3	0.2	0.4	0.3	0.4
4	0.4	0.3	0.4	0.2	0.3
5	0.4	0.3	0.3	0.2	0.1
6	0.4	0.4	0.4	0.3	0.2
7	0.5	0.3	0.6	0.3	0.2
8	0.5	0.3	0.6	0.3	0.2
9	0.5	0.4	0.6	0.2	0.2
10	0.4	0.4	0.6	0.4	0.2
11	0.5	0.3	0.7	0.2	0.2
12	0.3	0.3	0.6	0.3	0.2
13	6.8	5.2	18.7	0.5	0.3

TABLE 3.—NITRATE-NITROGEN IN SOILS FROM CHEMISTRY DIVISION PLOTS
(Expressed in p.p.m. oven-dry soil)

Treatment No.	Time of Analysis (weeks after treatment)				
	2 weeks	6 weeks	10 weeks	15 weeks	21 weeks
1	49	81	113	141	132
2	4	57	137	146	143
3	67	81	197	154	190
4	2	74	137	124	196
5	147	87	166	241	194
6	14	53	154	267	206
7	203	186	296	222	307
8	8	126	182	208	253
9	177	180	364	320	264
10	8	113	216	215	256
11	47	174	556	254	270
12	114	128	145	197	211
13	168	246	663	791	532

Table 3, however, it is shown that in these cases there are also large accumulations of nitrate-nitrogen, so that there is no evidence of nitrification being inhibited.

Table 2 shows that the content of nitrite-nitrogen is extremely low in practically all cases. As with ammonia, the exceptions are in Sample 13, after 2, 6, and 10 weeks, but as pointed out above there are also large accumulations of nitrate-nitrogen in these cases.

In examining the figures for nitrate-nitrogen as given in Table 3, it will be seen that the addition of stubble (with the exception of alfalfa stubble—Sample 13) causes a considerable reduction in the amount of nitrates present at the time of the first analysis. According to Waksman (11), this is to be expected when organic materials of a wide C : N ratio are introduced into soil. As the decomposition of the material proceeds and the C : N ratio becomes sufficiently narrow, there will be a normal

accumulation of nitrate-nitrogen in the soil. The fact that the addition of alfalfa stubble (Sample 13) did not cause a lowering of the nitrate content after two weeks, is probably due to the higher nitrogen content of this material. The amounts of nitrogen in the samples of stubble used were found to be as follows:—

Corn stubble	0.62% N
Timothy stubble	0.74% N
Alfalfa stubble	2.29% N
Oat stubble	0.59% N

The addition of $CaCO_3$ seems to have increased the accumulation of nitrate-nitrogen somewhat, if averages of the five analyses of each sample are compared. (Compare No. 1 with No. 5, and No. 2 with No. 6.) The effect of adding $MgCO_3$ was less than that of $CaCO_3$. No other effects of these treatments are apparent.

Second Series

The second series of experiments was run on soil samples from the Dominion Experimental Station at Harrow, Ont. The samples available were as follows:—

Sample 2. Soil on which timothy was grown in 1936.

Sample 3. Soil on which corn was grown in 1935 and where severe brown root rot was shown in 1936.

Sample 4. Soil on which corn was grown in 1936.

Sample 5—Soil on which no corn, timothy or tobacco had been grown since 1930.

All four were remoistened to about 60% of their water-holding capacity and kept in bottles as described for the first series. In addition, portions of Samples 2 and 5 were treated with various crop residues, as follows:—

Sample 2C—about 1.5% of corn stubble
Sample 2O—about 1.5% of oat stubble
Sample 2T—about 1.5% of timothy stubble
Sample 2A—about 1.5% of alfalfa stubble
Sample 5C—about 1.5% of corn stubble
Sample 5O—about 1.5% of oat stubble
Sample 5T—about 1.5% of timothy stubble.

Nitrites and nitrates, but not ammonia, were determined at weekly intervals for a period of several weeks, and the results obtained are presented in Tables 4 and 5. Results for the 4 untreated soils are grouped together, so that they can be more easily compared.

From Table 4 it can be seen that as in the first series, there was at no time any accumulation of nitrite-nitrogen, not even with the sample (2A) which received alfalfa stubble.

The results given in Table 5 would indicate that, of the 4 untreated soils, Sample 5 shows the highest and most rapid accumulation nitrates.

TABLE 4.—NITRITE-NITROGEN IN HARROW SOILS, INCUBATED AT ROOM TEMPERATURE
(Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)									
	1	2	3	4	5	6	7	8	9	10
Untreated soils										
No. 2	0.4	0.6	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.3
No. 3	0.3	0.3	1.0	0.4	0.7	0.3	0.2	0.3	0.2	0.3
No. 4	0.4	0.3	0.9	0.4	0.7	0.4	0.3	0.3	0.2	0.2
No. 5	0.5	0.4	0.7	0.8	0.7	0.4	0.2	0.4	0.3	0.3
Treated soils										
No. 2—untreated	0.4	0.6	0.5	0.5	0.5	0.5	0.3	0.5	0.4	0.3
No. 2+ corn stubble	0.4	0.5	0.9	0.3	0.8	0.7	0.5	0.3	0.4	0.4
No. 2+oat stubble	0.3	0.5	0.5	0.3	0.4	0.5	0.3	0.5	0.4	0.3
No. 2+timothy stubble	0.4	0.5	0.9	0.4	0.4	0.6	0.5	0.3	0.2	0.3
No. 2+ alfalfa stubble	0.4	0.4	0.8	0.6	0.8	0.7				
No. 5—untreated	0.5	0.4	0.7	0.8	0.7	0.4	0.2	0.4	0.3	0.3
No. 5+ corn stubble	0.4	0.3	0.6	0.7	0.4	0.3	0.3	0.5	0.3	0.3
No. 5+oat stubble	0.5	0.3	0.7	0.7	0.5	0.3	0.3	0.5	0.3	0.2
No. 5+timothy stubble	0.4	0.4	0.8	1.0	0.6	0.4	0.2	0.3	0.3	0.2

TABLE 5.—NITRATE-NITROGEN IN HARROW SOILS, INCUBATED AT ROOM TEMPERATURE
(Expressed in p.p.m. oven dry soil)

Sample	Time of Analysis (weeks after treatment)									
	1	2	3	4	5	6	7	8	9	10
Untreated soils										
No. 2	35	50	63	83	66	100	153	141	178	133
No. 3	10	27	58	71	68	117	111	124	144	127
No. 4	30	32	36	40	90	61	84	88	184	196
No. 5	55	64	176	195	229	171	295	277	265	316
Treated soils										
No. 2—untreated	35	50	63	83	66	100	153	141	178	133
No. 2+ corn stubble	7	8	5	36	58	80	71	157	160	141
No. 2+oat stubble	6	5	5	3	4	Tr.	Tr.	Tr.	5	Tr.
No. 2+timothy stubble	4	4	12	8	15	18	39	82	96	95
No. 2+alfalfa stubble	9	107	451	728	760	656				
No. 5—untreated	55	64	176	195	229	171	295	277	265	316
No. 5+corn stubble	—	58	139	156	143	197	203	173	165	280
No. 5+oat stubble	—	Tr.	6	Tr.	Tr.	Tr.	4	5	13	29
No. 5+timothy stubble	25	30	54	108	112	114	180	171	188	213

It might be mentioned that this soil was obtained from a poultry paddock. It does not, however, show the highest percentage of total nitrogen as will be seen from the following figures:—

Sample 2.—0.080% total N.
Sample 3.—0.085% total N.
Sample 4.—0.064% total N.
Sample 5.—0.072% total N.

As in the first series, so also here, the addition of crop residues to the soil samples causes an initial depression in the amount of nitrates present. Even alfalfa has caused a low content of nitrates after one week, but in

two weeks the amount present is much above that in the untreated soil, which agrees with the results from the first series. Of the other three crop residues used, oats caused the most prolonged depression in amount of nitrates, with only a trace being present even after ten weeks with Sample 2. With Sample 5 however, a small accumulation is found after nine and ten weeks. In both soil samples, also, the effect of timothy residues in keeping down the accumulation of nitrates, is probably slightly more than the effect of the corn residues.

Third Series

The third series of experiments was run on Samples 3 and 4 from Harrow. These were treated with crop residues as were Samples 2 and 5 in the second series, but they were placed in the ice-box and allowed to incubate at a temperature of approximately 10° C. This procedure was suggested by the reported observation that brown root rot is favoured by low soil temperatures. In addition to determining the amount of ammonia, nitrite-, and nitrate-nitrogen at intervals, it was decided to determine exchangeable hydrogen and exchangeable calcium as well.

To obtain the exchangeable bases, 50 grams of soil were treated with about 100 cc. of neutral normal ammonium acetate solution, filtered and washed with more of the solution until the filtrate measured 200 cc. A 50 cc. aliquot was then titrated potentiometrically, using N/5 NH_4OH, until a reading corresponding to the pH of the neutral ammonium acetate solution was reached, the exchangeable hydrogen being calculated from the amount of standard ammonium hydroxide used. The remaining 150 cc. of solution was taken to dryness after being acidified with a few drops of conc. HCl, ignited at 450°–500° C. to destroy organic matter, and calcium was determined in the residue by standard procedure.

The results obtained in this series are presented in Tables 6, 7, 8, 9, and 10. The amount of ammonia present exceeds 10 p.p.m. in only 3 cases at the time of the first analysis, and in most of the other cases it is quite low. There is no appreciable amount of nitrite-nitrogen at any time.

In Table 8, the effect of adding stubble on the accumulation of nitrates in the soil samples is again shown. The effect of the oat stubble persists

TABLE 6.—AMMONIA NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
No. 3—untreated	11.9	7.6	2.9	1.0	7.8	5.1
No. 3+corn stubble	6.6	—	0.5	0.9	6.9	8.1
No. 3+oat stubble	12.0	1.4	1.4	2.8	8.1	5.5
No. 3+timothy stubble	2.9	1.9	2.9	0.9	—	—
No. 4—untreated	5.8	2.9	3.4	3.8	7.5	8.2
No. 4+corn stubble	0.5	2.9	1.4	1.0	6.3	6.6
No. 4+oat stubble	14.4	1.0	1.4	0.5	5.8	2.3
No. 4+timothy stubble	0	0.5	1.4	1.4	7.2	5.1

TABLE 7.—NITRITE-NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3—untreated	0.2	0.2	0.2	0.2	—	0.3
3+corn stubble	0.3	0.3	0.3	0.3	—	0.3
3+oat stubble	0.3	0.2	0.3	0.2	—	0.5
3+timothy stubble	0.2	0.2	0.3	0.3	—	—
4—untreated	0.3	0.2	0.3	0.4	—	0.5
4+corn stubble	0.2	0.2	0.3	0.3	—	0.2
4+oat stubble	0.2	0.2	0.3	0.3	—	0.3
4+timothy stubble	0.2	0.2	0.3	0.4	—	0.2

TABLE 8.—NITRATE-NITROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in p.p.m. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3—untreated	15	78	98	181	103	99
3+corn stubble	4	Tr.	6	39	77	129
3+oat stubble	8	Tr.	4	5	4	7
3+timothy stubble	5	Tr.	4	11	23	—
4—untreated	15	31	36	32	54	55
4+corn stubble	10	Tr.	4	3	13	37
4+oat stubble	12	Tr.	4	3	Tr.	7
4+timothy stubble	4	Tr.	4	3	Tr.	14

TABLE 9.—EXCHANGEABLE HYDROGEN IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in milliequivalents per 100 g. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3 untreated	3.0	2.6	2.9	2.6	2.7	3.6
3+corn stubble	2.8	2.5	2.7	2.2	2.4	3.6
3+oat stubble	3.3	2.8	2.6	2.4	2.2	2.9
3+timothy stubble	3.0	2.1	2.9	2.2	2.4	—
4—untreated	3.3	2.7	3.1	2.6	2.4	3.1
4+corn subble	4.0	2.8	2.9	2.7	2.5	3.3
4+oat stubble	3.3	3.0	3.1	2.4	2.4	3.6
4+timothy stubble	3.7	2.7	2.6	2.4	2.4	3.1

TABLE 10.—EXCHANGEABLE CALCIUM IN HARROW SOILS, INCUBATED AT 10° C.
(Expressed in milliequivalents per 100 g. oven-dry soil)

Sample	Time of Analysis (weeks after treatment)					
	1	3	5	9	16	22
3–untreated	2.6	2.8	2.7	2.7	2.7	2.8
3+corn stubble	2.7	2.9	2.9	2.7	2.8	2.9
3+oat stubble	2.8	3.5	3.6	3.4	3.1	3.3
3+timothy stubble	2.8	3.1	3.0	3.0	2.8	—
4—untreated	2.7	2.9	2.8	2.8	2.7	2.9
4+corn stubble	2.8	2.9	2.9	2.8	2.8	3.0
4+oat stubble	2.9	3.1	3.0	3.0	3.0	3.2
4+timothy stubble	2.9	3.1	3.1	3.0	2.9	3.2

longest, and the effect of the corn stubble seems to disappear before that of the timothy stubble. This agrees with the results of the second series.

The variations in the amounts of exchangeable calcium and exchangeable hydrogen are small. There seems to be no effect on these two constituents from the addition of stubble, which, in the case of the hydrogen, may be interpreted to mean that there is no appreciable change in the acidity of the soil due to these treatments.

SUMMARY

Soil samples from the Chemistry Division plots at the Central Experimental Farm, Ottawa, and from the Dominion Experimental Farm at Harrow, Ont., were treated with the ground-up residues (stubble and roots) of corn, timothy, oats and alfalfa, and maintained at a moisture content corresponding to about 60% of the water-holding capacity of the soils. Two series were kept at room temperature (about 20°–25° C.) and a third at about 10° C. Analyses were made at intervals for ammonia, nitrite-, and nitrate-nitrogen. The following conclusions are drawn from the results obtained:—

1. The addition of the residues of these plants does not cause any appreciable accumulation of ammonia in the soil. One exception is shown in one case with alfalfa stubble, but in that case there is also a large accumulation of nitrate-nitrogen.

2. The addition of the residues of these plants does not cause any appreciable accumulation of nitrites in the soil (with the one exception mentioned under 1).

3. All residues cause an initial depression in the accumulation of nitrates. The effect of alfalfa was quite brief, that of corn was less than that of timothy, and that of oats lasted longest.

4. Incubation of soil samples at 10° C. did not cause any accumulation of ammonia or nitrites, and nitrates accumulated as would be expected, perhaps somewhat more slowly due to the effect of the lower temperature on the activities of the microorganisms.

5. The addition of these plant residues seems to have no effect on the exchangeable hydrogen or exchangeable calcium.

6. It does not appear from these studies that corn or timothy residues (brown root rot of tobacco seems to follow both of these crops) have any more pronounced effect on the three forms of nitrogen studied than has oats residues, when the same amount of each is added to the soil. All depress the initial accumulation of nitrates, but the effect of corn and timothy disappear before that of oats.

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THE CHEMICAL COMPOSITION OF RUSSIAN THISTLE (*SALSOLA PESTIFER* A. NELS)[1]

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Russian thistle (*Salsola pestifer* A. Nels) is an annual weed thought to have been introduced to the Dakotas from Russia about 1873. Although classified as a secondary noxious weed, it has in recent years become widespread throughout the desert plains and foothill areas of the United States and in the southern parts of Alberta, Saskatchewan and Manitoba. It is well adapted to dry conditions, and consequently, although it cannot compete successfully with a good stand of grain, will thrive where crops have failed owing to drought. By its rapid invasion of lands permanently or temporarily abandoned, it has retarded soil drifting and served as an emergency feed when nothing else has been available. Owing to its spiny leaves, high ash content, and its rigid, bulky structure, which makes it difficult to cure and store, it is not to be considered a particularly desirable feed. However, the severe drought in Saskatchewan during the season of 1937 forced many farmers to use it as livestock feed. As little information regarding its feeding value was available, it was thought necessary to study some of the problems connected with its use. A general discussion of the practical aspects of utilization of Russian thistle as livestock feed has already been published (2). It is the purpose of this paper to present the analyses made on a series of samples gathered at various stages of maturity and from various types of soil.

The samples were obtained from the environs of Saskatoon between July 31 and October 18, 1937 and were selected to represent different stages of growth from early bloom to complete ripeness, when the plants were ready to break off at the ground level.

The analyses are given in Table 1. For comparison there is presented in Table 2 a summary of analyses made on some of the commonly used leguminous and non-leguminous hays.

Before discussing the data in Table 1, we must point out that certain anomalies appear, which, although inexplicable, need to be included, if for no other reason than that we cannot account for them. For instance, the two samples gathered on September 16 were unaccountably low in protein and ash and high in fibre. The analyses of these particular samples were repeated and they checked. It should be kept in mind that a carefully planned growing experiment, with replication to eliminate variation due to soil and other environmental factors, would be difficult to carry out, because it requires drought conditions to make this plant flourish typically. Consequently this study was more or less fortuitous and it was necessary to get material where it could be obtained. As much care as possible was exercised to select plants at various stages of growth, but it was not always

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possible to find them growing within a small area. A record was kept of the general type of soil on which they grew so that they could be segregated into two classes, those from heavy soil and those from light soil. Despite these shortcomings, the data here presented seem to justify certain conclusions regarding the composition of Russian thistle which may be of interest.

Table 1 shows that the plants at the flowering stage were exceedingly high in ash, quite high in protein, and relatively low in crude fibre. With advancing maturity, there was a very marked reduction in relative ash content, a moderate decrease in protein content and increases in crude fibre and fat. The nitrogen-free extract remained almost unchanged over the 78-day period. Probably the change in ash content is the most important. It has been supposed that the high ash was responsible for the "scouring" that follows the extensive feeding of Russian thistle. The reduction of ash content with maturity is consistent with observations that older plants cause less scouring than young plants.

Although there was a marked increase of crude fibre content with maturity, the highest values are about the same as for alfalfa and sweet clover and somewhat lower than for non-leguminous roughages such as timothy, western rye grass and red top hays, which according to our analyses average about 34% crude fibre.

TABLE 1.—COMPOSITION OF THE DRY MATTER OF RUSSIAN THISTLE AT VARIOUS STAGES OF GROWTH

Date of cutting	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
July 31—Early flowering	5	Max.	18.6	20.7	25.9	2.3	47.0
		Min.	14.7	10.4	21.4	1.5	38.2
		Average	16.7	15.4	23.5	1.9	42.5
August 7	4	Max.	18.2	23.3	19.0	1.9	50.1
		Min.	8.9	20.9	17.4	1.7	37.5
		Average	14.7	22.1	18.2	1.8	43.2
August 26	2	A	16.8	22.4	20.5	2.1	41.8
		B	16.5	18.8	17.9	1.7	41.5
		Average	16.7	20.6	19.2	1.9	41.7
September 16	2	A	10.7	28.7	13.6	3.8	43.9
		B	10.4	28.6	13.6	3.3	43.4
		Average	10.5	28.6	13.6	3.6	43.6
September 23	2	A	14.7	25.8	16.1	5.8	41.6
		B	12.2	23.0	15.6	4.9	40.4
		Average	13.4	24.4	15.8	5.4	41.0
October 5	2	A	15.3	28.8	13.7	5.6	38.7
		B	14.7	27.6	12.7	5.1	37.7
		Average	15.0	28.2	13.2	5.3	38.2
October 18—Fully mature	2	A	14.4	29.4	11.8	5.3	42.7
		B	13.6	25.8	9.7	5.3	42.1
		Average	14.0	27.6	10.8	5.3	42.4

TABLE 2.—SUMMARY OF ANALYSES OF HAYS PRODUCED IN VARIOUS LOCALITIES OF NORTHERN SASKATCHEWAN*

Variety	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
Alfalfa	18	Max.	22.6	36.1	12.8	3.8	46.1
		Min.	14.8	24.9	7.6	1.9	33.1
		Average	16.2	29.4	9.9	2.6	40.3
Sweet clover	16	Max.	22.4	38.9	13.0	3.7	46.7
		Min.	14.1	20.8	7.1	1.8	35.4
		Average	17.5	27.8	10.3	2.6	41.8
Timothy	7	Max.	9.2	42.4	9.1	3.2	53.4
		Min.	6.8	28.6	5.1	2.0	40.0
		Average	8.2	32.6	6.8	2.5	49.8
Western rye grass	5	Max.	12.6	36.0	9.4	3.5	46.2
		Min.	9.2	32.4	5.2	2.9	42.3
		Average	10.9	34.7	6.7	3.2	44.4
Red top	5	Max.	12.3	37.7	10.2	2.7	52.7
		Min.	6.8	30.0	5.6	2.2	37.4
		Average	9.4	33.5	7.9	2.5	46.7

* These analyses were made on samples which had been cut and cured at the stage of growth considered best for the production of good hay.

The crude protein content decreased with advancing maturity, but even in ripe plants was markedly higher than in non-leguminous hays but somewhat lower than in leguminous hays. The values are roughly: legume hay 17%, Russian thistle 14%, and non-leguminous hays 9.5%. Plants harvested in the flowering stage and cured would have a protein content averaging practically the same as alfalfa.

The nitrogen-free extract, which is an estimate of the soluble and easily hydrolyzable carbohydrates, showed little variation over the growth period investigated. The values average about 42% and are about the same as for alfalfa, sweet clover and western rye grass, hays which were found to be 40.3, 41.8 and 44.4% respectively; they are somewhat lower than that of timothy and red top hays.

On the basis of composition alone, mature Russian thistle compares favourably with alfalfa hay in all components. It would not, however, be suggested that they are equal in feeding value, because the spiny nature of the dry plant makes it objectionable and it is generally recognized that it is rather unpalatable. Esplin, Greaves and Stoddart (1) estimate its palatability for sheep at 30–40 (100 for maximum palatability). However, animals on restricted rations will eat Russian thistle quite readily and it is interesting to know how favourably it compares with the standard forages in composition.

These data also indicate how the wide difference in various reported analyses, summarized by Walker (3), may be reconciled. It seems probable that these differences result from taking the plant at different stages of maturity.

Effect of Soil on Composition of Russian Thistle

In view of some of the irregularities shown in Table 1, it was thought desirable to find what effect, if any, different soil types might have on the composition of the plant. Accordingly, five samples were obtained from each of two distinct soils, a clay loam and a sandy loam soil. The analyses of these samples are summarized in Table 3.

TABLE 3.—THE EFFECT OF SOIL TYPE ON COMPOSITION OF RUSSIAN THISTLE

Soil type	No. of samples		Percentage composition on moisture-free basis				
			Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
Clay loam	5	Max.	18.6	20.8	25.9	2.3	47.0
		Min.	14.7	10.4	21.4	1.5	38.2
		Average	16.7	15.4	23.5	1.9	42.5
Sandy loam	5	Max.	18.4	23.3	23.0	1.9	50.1
		Min.	14.5	16.5	17.4	1.7	37.5
		Average	15.4	21.0	19.2	1.8	42.6

Although the nature of the sampling does not warrant any hard and fast conclusions, the data in Table 3 indicate that plants grown on the heavier soil were lower in crude fibre and higher in crude ash than those grown on the lighter soil. The other components showed no appreciable differentiation. Low fibre and high ash are characteristics of the more immature plants and the values obtained with plants grown on the heavier soil might be accounted for by assuming that this soil had more available water in it than the light soil and that the ripening of the plants was therefore retarded. The greatest care possible, however, was exercised in gathering the samples to get them at similar stages of growth from each soil and we conclude therefore that the heavier soil is likely to produce Russian thistle plants of higher ash content than light soils.

Comparison of Plants of Different Sizes

Russian thistle plants vary greatly in size. Those growing in patches, thickly seeded, suffer from heavy competition and tend to be spindly and short even when mature, while those not checked by competition become extremely branchy and may attain a height of 2 feet and a diameter of 3 feet. A question arose concerning the composition of the dwarfed and the luxuriant plants. Some of the data already tabulated were rearranged on this basis. The average values for the two classes of plants did not justify the conclusion that they are differentiated.

Composition of Tops, Crowns and Roots

The common practice is to cut Russian thistle with the mower, but in some circumstances the growth on summerfallow or other cultivated land has been such that this has not been practicable and the cultivator or rod-weeder has been used. Plants harvested in this manner have most of the

root adhering and it was necessary therefore to get some idea of the effect on feeding value of including the roots. Samples of tops, crowns and roots from one lot of plants were prepared and analysed.

TABLE 4.—COMPOSITION OF TOPS, CROWNS AND ROOTS OF RUSSIAN THISTLE

	Percentage composition on moisture-free basis				
	Crude protein	Crude fibre	Crude ash	Crude fat	Nitrogen-free extract
Tops	18.4	16.5	23.0	1.8	40.3
Crowns	7.4	40.2	11.5	0.7	40.5
Roots	7.2	45.3	7.8	0.6	39.0
Oat straw (2 analyses)	5.2	43.1	7.8	2.0	41.8

It can be seen from Table 4 that the crowns and roots are much lower than the tops in respect to crude protein and crude ash, very much higher in fibre and about the same in nitrogen-free extract. Inclusion of the roots would therefore lower the feeding value of the material. It is interesting to note, however, that the composition of the roots of Russian thistle compares favourably with the composition of oat straw which is frequently used as a roughage.

SUMMARY

Analyses of Russian thistle collected at various stages of growth from early bloom to complete maturity showed that with advancing maturity there is a marked reduction in ash content, some reduction in protein content, an increase in fat and fibre and little change in nitrogen-free extract. At maturity the composition of the plant is not much different from that of alfalfa hay.

Samples from clay loam soil were higher in ash and protein and lower in fibre than those from sandy loam soil.

The crowns and roots of the plant are very much lower in protein and ash and very much higher in fibre than the tops. The roots are similar to oat straw in composition.

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A PRELIMINARY INVESTIGATION OF THE VALUE OF CORN DISTILLERS' DRIED GRAINS IN CHICK RATIONS[1]

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INTRODUCTION

Because of the expansion of the distilling and brewing industries during the past few years, their by-products, such as distillers' grains, brewers' grains and so forth, have tended to accumulate on the market. The amount of these products available during prohibition years was not large and little research with regard to their feeding value was done. This is especially true of poultry feeding, since the majority of the formulae for poultry rations now in use have been developed during the past ten years. At the time this research was done, these by-products were relatively cheap being quoted at 1 to 1½ cents per pound. If they can be used satisfactorily in chick rations they would tend to lower the cost. In so far as the authors are aware, no experimental work has been done with regard to the value of distillers' dried grains in chick ration, but since the completion of this work, Insko, Buckner, Martin and Harms (2) and Buckner, Insko, Martin and Harms (13) have studied the value of distillers' dried grains and distillery slop in growing and fattening rations.

In the manufacture of alcohol and distilled liquors from cereals, the corn, rye or barley, after being ground is treated with a solution of malt to convert the starch into sugar, which, in turn, is converted into alcohol by the action of yeast. The alcohol is distilled off, leaving a watery residue known as distillers' slops. The solid matter is usually drained out and dried in vacuum, forming dried distillers' grains or distillers' dried grains, which are sold. This by-product consists of the portions of the grain not acted upon during the fermentation process, that is, the crude protein, fibre, fat and the more insoluble part of the nitrogen-free extract. In addition, it contains appreciable amounts of the yeast formed during the fermentation. As there is a difference in the composition and livestock feeding value of distillers' grains produced from different grains, they are usually called corn distillers' dried grains[4] or rye distillers' dried grains, depending upon which grain predominates. It would appear that the nutritive value of these grains in poultry rations may depend not only upon their protein or mineral content but probably includes their content of the vitamin B complex.

Corn distillers' dried grains contain from 28 to 32% crude protein, averaging about 30%, with from 9 to 11% fat and about 11% fibre. According to Morrison (17) they furnish 85 pounds of total digestible nutrients per 100 pounds, which is more than supplied by such feeds as

[1] This work formed the undergraduate thesis of one of the authors (R.T.A.) submitted in fulfilment of the requirements for the degree of Bachelor of Science of Agriculture, 1936.

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[4] There appears to be some difference of opinion as to the correct name of these feeds. We have used the term "corn distillers' dried grains" since it is the name used in The Feeding Stuffs Act, 1937, and in the official publication of the Association of American Feed Control Officials, 1936. On the other hand, Morrison (15) refers to this product as "Distillers' corn dried grains" and the terms "dried distillers' corn grains" or "distillers' dried corn grains" are also in use.

corn, corn gluten feed, linseed meal or cottonseed meal. He further states that they are "deservedly a popular feed for dairy cattle," but points out that because of their bulkiness they should not comprise more than 15 to 20% of the ration for pigs. Although the question of the digestion and utilization of crude fibre by poultry is by no means settled, as pointed out by Mangold (15), the above statement probably holds true also for poultry.

As Halpin and Holmes (7) and Halpin, Holmes and Hart (8, 9) have shown that rye is not a satisfactory grain for chicks, corn distillers' dried grains were used in this preliminary experiment. This product analyzed 5.3% moisture, 31.4% crude protein (N × 6.25), 5.0% fat, 13.1% crude fibre and 1.3% ash. Previous experiments in this laboratory, Stephens (19), indicated that corn gluten feed could be satisfactorily used as a part of the protein supplement in chick rations. Hence, it was considered that the protein in corn distillers' dried grains might also be valuable. In order to obtain some information with regard to the vitamin B complex, dried brewers' yeast and wheat germ, which are known to be good sources of this complex, were compared with the distillers' grains.

The term "vitamin B complex" is used to designate a group of water soluble vitamins. This group includes B_1 or B (antineuritic), B_2 or G or flavin (growth promoting), B_3 (pigeon weight maintenance, possibly required by the chick), B_4 (rat growth and required by the chick), B_5 (pigeon growth factor), B_6 (rat antidermatitis), and several others. Vitamin B_2 has been used by some workers to designate the heat stable fraction of the vitamin B complex. If this terminology is used, then vitamin B_2 must be considered as itself consisting of several factors. At the present time it is also impossible to correlate the requirements of various types of "experimental animals" for the various fractions of the vitamin B complex.

Although poultry require vitamin B_1 in order to prevent avian polyneuritis, it is present in the germ and bran of all grains. Since grains and their products constitute a large part of poultry rations, this vitamin should not be deficient in ordinary rations, unless they have been heated. Vitamin B_2 (G) as originally postulated in poultry nutrition was a complex. The term vitamin B_2 or G is now, with few exceptions, used to designate riboflavin (lactoflavin or hepatoflavin) which is required by poultry for growth and is an important factor in hatchability. Chicks also require some part of this complex in order to prevent the onset of nutritional paralysis, a disease in which the birds walk on their hocks with the toes characteristically curled inward. The bulk of the evidence indicates that this nutritional paralysis is caused by a deficiency in flavin, but there is some evidence that a separate factor is involved. Riboflavin is furnished in poultry rations by milk, whey, liver, grass, alfalfa, etc.

Riboflavin has no effect on chick dermatitis (pellagra). For a time it appeared that two factors were concerned in chick dermatitis. This confusion arose through the similarity in the appearance of the symptoms produced in chicks as a result of egg white feeding, and the dermatitis produced by feeding a heated diet of natural foodstuffs. It is now established that the egg white syndrome has an entirely different etiology from the heated diet dermatitis and that chick dermatitis is caused by a deficiency of one factor, variously referred to as the antidermatitis, antipellagric or Factor 2 of the filtrate factor (generally spoken of as "the filtrate factor").

The chick antidermatitis factor is quite distinct from the factor (B_6 or Factor 1 of the filtrate factor) which prevents dermatitis in rats or that which prevents pellagra in humans (nicotinic acid). It is also growth-promoting in chicks.

A deficiency of vitamin B_4 in poultry rations results in lowered growth, inco-ordination and paralysis. In the earlier work this paralysis was confused with nutritional paralysis and it was considered also that it was identical with nutritional encephalomalacia. These are considered now to be three separate and distinct abnormalities. It is doubtful if chicks require B_3, B_5, or B_6.

These water-soluble factors of the vitamin B complex appear to have a common characteristic in that they all occur in yeast. There has been considerable controversy as to whether the usual type of poultry rations which contain considerable quantities of cereal grains or their products, are improved by the addition of yeast, usually added as dried brewers' yeast.

Dougherty (3) stated that the addition of pure dried granulated yeast to a standard ration stimulated appetite and materially increased the growth rate even when chicks were fed liberal amounts of green feed. Mussehl and Ackerson (18) concluded that the growth rate of chicks was increased by the addition of yeast to certain chick rations which contained at least 75% of cereal products. The improved growth rate may have been due either to protein or to vitamin B_2 contributions. Gerhardt (4) also reported that the addition of 3% yeast to a normal ration resulted in better food consumption and growth.

Hamilton, Cark and Kick (10) concluded that a ration for growing chicks containing 60% of ground whole grains (corn, oats and wheat) and 20% of other seed products was apparently not deficient in vitamin B. For chicks reared under laboratory conditions there was a suggestion, however, that the addition of yeast enhanced the nutritive value of the ration.

On the other hand, Bethke and Kennard (1) stated that a ration containing 63% or more of whole grains (corn and wheat) and 10% of other seed products (soyabean oil meal and wheat bran) and 20% of either meat scraps or dried buttermilk, with adequate mineral and fat-soluble vitamin supplements, was found to meet the vitamin B requirement of growing chicks kept for ten weeks on wire floors.

There are certain possibilities for this variation in the results of supplemental yeast feeding. First, there would undoubtedly be a difference in the amounts of the various fractions of the vitamin B complex furnished by the basal diets. Vitamin B_2 (riboflavin) and the chick antidermatitis factor, although these latter are furnished to some extent by cereal grains, are probably the fractions involved. Secondly, there is a variation in the vitamin content of various types and strains of yeast, dependent to a considerable extent upon the culture media. Thirdly, there is the probability that yeast alone does not furnish all the water-soluble factors required by chicks. Experiments conducted in this laboratory, Graham, Pettit, Sykes and Howell (6) and van der Hoorn (20) and elsewhere, Hogan and Shrewsbury (12), have shown, by the use of simplified diets, that,

when used as the sole vitamin B complex supplement, it required about 30 to 40% dried brewers' yeast or about 30% wheat germ to meet these requirements. On the other hand, a combination of 10 to 15% yeast with 10% wheat germ gave more satisfactory results. Hogan and Boucher (11) and Keenan, Kline, Elvehjem, Hart and Halpin (14) have used various extracts of liver to supplement the yeast in such diets. It is possible that some supplementary effect between the various factors in the vitamin B complex or a deficiency in some factor of this complex may also be involved.

McConachie, Graham and Branion (16), to whom the reader is referred for a review of similar investigations, concluded that the optimum amount of crude protein in a ration for growing chicks to 12 weeks of age was approximately 19%.

EXPERIMENTAL

The composition of the various rations fed, together with their approximate analyses is shown in Table 1. Thirty newly hatched Barred Plymouth Rock chicks were started on each ration. The birds were kept indoors in single tier, wire floored, battery brooders. They were individually weighed

TABLE 1.—COMPOSITION OF RATIONS (Pounds)

Ingredients	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8	Diet 9	Diet 10
Ground yellow corn	25	25	25	25	25	25	25	25	20	25
Ground wheat	25	25	25	25	25	25	25	25	20	25
Ground oats	25	25	25	25	25	25	25	25	20	25
Ground barley	25	25	25	25	25	25	25	25	20	25
Alfalfa meal	5	5	5	5	5	5	5	5	5	5
Fish meal	5	5	5	5	5	5	5	5	5	4
Meat meal	5	5	5	5	5	5	5	5	5	4
Dried buttermilk	5	5	5	5	5	5	5	5	5	5
Dried brewers' yeast		5						2½		
Wheat germ			5	10			5	5		
Corn distillers' dried grains					5	10	5		20	5
Bone meal	1	1	1	1	1	1	1	1	1	1
Oyster shell	2	2	2	2	2	2	2	2	2	2
Salt	½	½	½	½	½	½	½	½	½	½
Cod liver oil	1	1	1	1	1	1	1	1	1	1
Per cent crude protein (N × 6.25)	16.4	17.5	16.8	17.1	16.8	17.1	17.1	17.3	18.8	16.1
Per cent crude fibre	5.5	5.3	5.3	5.2	5.8	6.1	5.6	5.3	6.9	5.9
Per cent ash	7.3	7.4	7.2	7.4	7.2	7.1	7.1	7.3	7.5	6.9

each week to the nearest gram and at the end of the experimental period of 10 weeks, they were examined for percentage feathering over the back. Feed consumption was recorded. The chicks were allowed unrestricted access to insoluble grit.

The ration fed to Group 1 was a "chick starter" ration which has been used with reasonable success at the Department of Poultry Husbandry. It is not a high protein ration and hence does not grow chicks quite as rapidly as some rations, but considered over the whole growth period, its use results in birds which compare very favourably with most similar rations. This group served as a control. In Group 2 this ration was supplemented with 5 pounds of dried brewers' yeast which raised the crude

protein content about 1%. It is doubtful if this increase in protein content, or the difference in protein content between any of these rations, is sufficient to cause any difference in growth response. Since the brewers' yeast contained about twice as much crude protein as the wheat germ or the distillers' grains, the ration of Group 3 was supplemented with 5 pounds of wheat germ and that of Group 4 with double this quantity in order to furnish approximately the same amount of protein. Similarly the rations of Groups 5 and 6 were supplemented with 5 and 10 pounds, respectively, of the corn distillers' dried grains. The ration of Group 7 was supplemented by a combination of 5 pounds of wheat germ and 5 pounds of distillers' grains and that of Group 8 by a combination of $2\frac{1}{2}$ pounds of yeast and 5 pounds of wheat germ. In the ration of Group 9, twenty pounds of distillers' grains were used to replace 5 pounds each of wheat, corn, barley and oats. In the ration of Group 10, five pounds of distillers' grains were used to replace one pound each of the fish and meat meals.

A comparison of the results of Groups 2, 3 and 5 should show the relative value of equal quantities of yeast, wheat germ and distillers' grains, respectively, in supplementing the control ration (Group 1); while a comparison of Groups 2, 4 and 6 should show the relative value of the quantities of these three supplements supplying the same amount of protein. The results with Groups 7 and 8 should check the supplementary value of wheat germ and distillers' grains against yeast and wheat germ, with the total protein content of the rations approximately the same. Group 9 should give some indication of the value of distillers' grains as a cereal supplement, since, at its current price, it could compete with cereal grains, in addition to supplying 2 to 3 times the protein. In Group 10 an attempt was made to obtain some idea of the value of this protein in distillers' grains.

Since dried buttermilk is an excellent source of flavin, as well as containing some of the other factors in the B complex, its amount in these rations was not varied, in order to remove, in so far as possible, this complicating factor. No attempt was made to equalize the total ash content of these rations, but the variation does not appear to be appreciable.

The average weekly weights and the number of birds surviving at each weighing are shown in Table 2. The average weight of each group with the average weight of the cockerels and pullets in each group at 10 weeks of age, the percentage feathering over the back for each sex, the feed-gain ratio, the number of chicks with deformed legs (including bending, bowing and perosis) and the mortality are shown in Table 3. In calculating the feed gain ratio, or number of pounds of feed required to produce a pound gain, mortality is charged against the ration.

DISCUSSION

The growth response of Groups 2, 3, 4, 5, 6, 7 and 8 as compared to that of Group 1 indicated that supplementing the control diet with either yeast or wheat germ or corn distillers' dried grains or with a combination thereof, resulted in improved growth. As was pointed out, the greatest amount of additional protein furnished by any of these supplements was 1.1% over that of the control diet. It therefore would appear probable that the greater part of this extra growth, which with one exception (Group

6) was associated with more efficient food utilization, was due to some factor in these supplements, presumably in the vitamin B complex. In other words, feeding additional vitamin B complex was beneficial to chicks reared under laboratory conditions, in spite of the fact that a large part of the control ration consisted of cereal grains.

TABLE 2.—AVERAGE WEEKLY WEIGHTS (Grams)

Group	Weeks										
	0	1	2	3	4	5	6	7	8	9	10
1	30*	30	29	27	26	26	26	26	26	26	26
	34	62	87	124	157	226	291	383	494	600	697
2	30	30	30	30	30	30	30	30	30	30	30
	36	64	98	152	215	311	374	500	615	757	861
3	30	30	27	25	25	25	25	25	25	25	25
	34	65	93	135	181	274	354	457	574	696	822
4	30	30	28	24	24	24	24	24	24	24	24
	35	67	98	137	191	280	344	475	603	746	880
5	30	30	29	28	28	28	28	28	28	28	28
	31	65	97	144	197	283	365	487	618	757	857
6	30	30	27	24	24	24	24	24	24	24	24
	36	66	89	130	180	251	318	430	550	671	810
7	30	30	29	29	29	29	29	29	29	29	29
	33	73	98	152	209	301	345	473	591	714	852
8	30	30	29	28	28	28	28	28	28	28	28
	36	71	103	155	216	304	367	489	606	731	860
9	30	30	30	30	30	30	30	30	30	30	30
	36	66	96	148	198	300	367	478	592	731	859
10	30	30	30	29	29	29	29	29	29	29	28
	37	65	93	133	180	257	330	435	550	664	813

*Number of chicks surviving each week.

TABLE 3.—SUMMARY OF RESULTS AT TEN WEEKS

Group	Average weights			Feathering		Feed : Gain Ratio	Deformed legs	Mortality
	Group	Cockerels	Pullets	Cockerels	Pullets			
	grams	grams	grams	%	%		chicks	chicks
1	697	712	673	28	48	3.77	2	4
2	861	941	792	50	85	3.17	0	0
3	822	879	783	19	50	3.47	0	5
4	880	967	793	40	88	3.26	0	6
5	857	926	751	40	67	3.49	1	2
6	810	829	793	56	79	3.89	0	6
7	852	966	782	33	64	3.47	0	1
8	860	974	775	37	85	3.59	3	2
9	859	877	817	30	79	3.36	1	0
10	813	893	720	48	83	3.70	0	2

A comparison of the differences between the average weights of Groups 2, 3, 4, 5, 6, 7 and 8 with studies conducted under similar conditions in this laboratory indicated that there was no significant differences between the average weights of the birds in these groups. A difference of 100 to 150 grams is necessary for significance. No beneficial effect of combining these supplements in comparison to their individual use was evidenced.

The response of Group 9 would indicate that, within reasonable limits, at least to 20%, corn distillers' dried grains may be used satisfactorily to replace part of the cereal grain mixture in chick rations. The response of Group 10 would suggest that the protein in distillers' grains is worthy of further study, as a replacement for a part of the "animal" protein in such rations.

It will be observed from Table 3 that the percentage of feathering over the back has been improved, with the exception of Group 3, by the addition of these supplements to the ration. Although 5% wheat germ gave no improvement, increasing this supplement to 10% resulted in more feathering than the control group. Similarly, although 5% distillers' grains (Group 5) resulted in feathering superior to that of the controls, the addition of 10% (Group 6) gave more improvement.

Gerrick and Platt (5) found that feather development in Barred Plymouth Rock chicks was improved proportionally with increasing amounts of protein, up to the optimum, in the ration. McConachie, Graham and Branion (16) found a general relationship between feather development and the protein content of the diet, but suggested that the optimum protein level for growth was not necessarily the optimum protein level for best feather development. Both low and high protein levels upset the barred feather pattern. The protein of a ration is not the only nutritive factor concerned in feather development. There is evidence that the vitamin B complex is also concerned. It is probable, that other factors being equal, the nearer optimum the ration is in all nutritive factors, the better will be the feather development.

The severity of the deformed legs was slight in the few cases which did occur.

It should be borne in mind that the beneficial results in this preliminary investigation seem to be due chiefly to the additional vitamin B complex furnished by corn distillers' dried grains, dried yeast or wheat germ, but there is no strict proof. The results may have been due to other factors, such as minerals, or to a combination of such factors. Strictly speaking, this experiment only shows that under the conditions of this test, the addition of these supplements to the basal ration resulted in some improvement. Since yeast and wheat germ are known to be good sources of the vitamin B complex, one is inclined to consider that this group of vitamins was responsible for the improvement.

SUMMARY

The addition of wheat germ, dried brewers' yeast or corn distillers' dried grains, either singly or in combination, to an ordinary ration with the usual amount of cereal grains, fed to chicks under laboratory conditions, improved growth and feather development. This increased growth was

associated in general, with more efficient utilization of food. This improvement would appear to be associated with the additional amounts of the vitamin B complex furnished by these supplements.

These results, although preliminary, indicate that under confined conditions, the ordinary types of chick rations may be improved by additional vitamin B complex supplements. Corn distillers' dried grains would seem to be a reasonable source of this complex.

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THE MORPHOLOGY AND COMPOSITION OF SASKATCHEWAN PODZOLIC SOILS[1]

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The four major soil zones of Saskatchewan have been established on the basis of regional soil profiles which reflect the broad differences in climate and vegetation found throughout the province (13). The most northerly soil region so far investigated is known as the gray soil zone and is characterized by gray (podzolic) soils, a wooded (forest) vegetation and a cool sub-humid climate.

The present study is concerned with the more important soil profiles encountered in the southern portion of the gray soil zone and in the transition belt between the gray and black soils. The investigation covers the morphology, composition and environmental features of Saskatchewan podzolic soils, and also serves to illustrate the natural conditions found in the newly settled areas of the province. The field studies of the wooded soils were carried out in conjunction with the work of the Saskatchewan soil survey, a co-operative project of the Dominion and Provincial departments of agriculture. During the course of the survey a large number of soil profiles were examined, and certain representative types were sampled for laboratory study. The chemical data presented represent percentages of soil constituents as determined by methods of total analysis, expressed on a moisture free basis.

DESCRIPTION OF THE AREA

Location and Extent.

The province of Saskatchewan extends from 49° to 60° North latitude and from about 101° 30′ to 110° West longitude. Approximately 150,000 square miles, or 60% of the total area, is included in the gray soil zone, which extends into the Pre-Cambrian region of northern Saskatchewan. No soil investigations have yet been made in the latter region. The area covered by the present study lies along the southern borders of the gray soil zone, roughly between 52° and 53° 40′ North latitude.

Surface Features

The surface topography ranges from nearly level to rolling and hilly, and the altitude varies from 1100 to 2200 feet above sea level. The slope is mainly to the northeast and most of the area is drained by the Saskatchewan river and its tributaries, whose waters ultimately flow into Hudson bay.

Local drainage of upland areas is usually adequate, and may be excessive on soils of rough topography or light texture. The lower lands and depressions are frequently poorly drained, and contain many lakes and peat bogs.

[1] This paper is based upon a thesis submitted to the University of Alberta in partial fulfilment of the requirements for the degree of Master of Science, and also upon the subsequent studies at the University of Saskatchewan.

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The surface geology consists chiefly of glacial morainic, lacustrine and alluvial deposits, the latter occasionally modified by wind action. Recent deposits are represented by peat bogs and shallow marshy areas.

Climate

The climate of the area is typical of north temperatue continental regions, and is characterized by relatively low precipitation and by wide extremes in temperature. Meteorological data are incomplete, but such records as are available indicate an average annual precipitation of about 15.5 inches, an average annual temperature of 30° to 31° F., and a frost-free period of approximately 100 to 110 days.

Vegetation

The vegetation of the wooded region is predominantly a forest cover of trees and shrubs. The southern part of the region, bordering the black soil zone, is covered chiefly with deciduous trees, largely aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*) with some canoe birch (*Betula papurifer*). Some coniferous trees also occur, notably jack pine (*Pinus Banksiana*), white spruce (*Picea Canadensis*) and tamarack (*Larix Americana*). Numerous shrubs are also common such as willows (*salix* spp.), hazelnut (*Corylus rostrata*), dogwood (*svida instolonea*), wild cranberry (*viburnum opulus*), alder (*Alnus incana*), Saskatoon berry (*Amelanchier alnifolia*). In the muskegs or bogs, marsh grasses, sedges (*Carex* spp.) sphagnum moss, and Labrador tea (*Ledum groenlandicum*) are found, often in association with small spruce and tamarack. In the more northerly portion of the province coniferous trees predominate, although the aspen and poplar are common to the whole of the forest region.

Soils

The soils of the area may be placed in two main groups: podzolic upland types, and peat soils of poorly drained positions. The podzolic soils vary in morphological character from slightly degraded black soils to well developed ashy-gray podzols. These profile variations are related to differences in parent materials, topographic position and vegetative cover, the more strongly leached soils being associated with well drained positions and medium to light textured parent materials.

The most extensive of the podzolic upland soils are those developed on glacial till and morainic deposits under a forest cover of deciduous trees and occasional clumps of spruce. Other profiles encountered are podzolic fine sands on alluvial deposits, chiefly under jackpine vegetation, and degraded black soils on heavy lacustrine deposits. Small areas of degraded black soils are also found on glacial till and sandy alluvial materials. The degraded black soils are transitional types between the black and gray soil zones and also occur as islands within the gray soil zone itself.

The peat soils vary in depth of the raw peat layer, reaction, and nativ vegetation. High lime peats are most common, occurring under sedge and marsh grasses. The more acid peats are associated with a sphagnum and tamarack vegetation, but even these are alkaline in the lower horizons. Calcareous black soils and podzolic peats are sometimes found around the borders of the marshes and bogs.

Agriculture

The agricultural development of the area is closely related to the natural factors discussed above, and in particular to the soil type. The degraded black heavy lacustrine soils are the most productive, followed by the lighter textured degraded soils. The podzolic glacial types are less fertile, and require good management and special crops to ensure satisfactory development. The podzolic sands are non-arable soils, while very few of the peat areas have been brought under cultivation to date. The factors responsible for these variations in productive capacity are indicated by the following data, and are also discussed in the latest soil survey report (13).

MORPHOLOGY AND COMPOSITION OF SOIL PROFILES

Profile No. 1

Located near Sturgis, Saskatchewan. Podzolised loam on glacial till deposits. Undulating to gently rolling in vicinity, with heavy stand of aspen.

A_0	0 – ½″	Black raw humus layer.
A_1	½ – 4″	Gray loam, coarse and gritty; faint platy structure, easily crushed.
A_2	4 – 8″	Ashy gray loam, similar to above, but with less organic matter.
B_1	8 – 18″	Gray brown heavy clay loam, gritty; compact, breaking into angular fragments.
B_2	18 – 22″	Dark brown clay, stony; compact, nutty to coarse granular structure.
C_1	22″+	Light gray heavy loam, stony; fine granular structure, calcareous.

Chemical Analysis of Profile No. 1.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	7.76	29.50	1.07	.097	53.05	8.44	2.30	—	7.1
A_1	0.70	2.82	.081	.033	80.20	10.93	1.16	—	6.9
A_2	0.72	1.70	.046	.021	79.04	12.25	0.84	0	7.0
B_1	2.34	2.60	.062	.026	75.60	15.74	1.10	0	6.7
B_2	3.10	2.16	.053	.044	70.50	16.88	1.40	0.29	7.0
C_1	0.70	1.34	.020	.042	62.25	14.25	4.96	7.23	8.1

Profile No. 2

Located near Crooked river. Podzolised heavy loam on glacial till. Undulating upland topography, aspen vegetation, with willow and spruce in low areas.

A_1	0 – 1″	Grayish black mixed organic and mineral layer, true A_0 having been destoyed by fire.
A_2	1 – 8″	Ashy gray heavy loam, gritty. Faintly platy, easily crushed.
B_1	8 – 14″	Coffee brown clay. Compact, breaking to coarse hard granules. Slightly calcareous.
B_2	14 – 18″	Brown to yellow-brown clay, stony. Structure as above. Calcareous.
C_1	18 – 55″	Dark gray clay, gritty. Coarse granular, calcareous.

Chemical Analysis of Profile No. 2.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_1	2.00	8.80	.341	.100	72.40	9.71	1.76	—	7.5
A_2	1.39	1.98	.067	.050	80.30	12.91	0.95	—	6.8
B_1	3.54	4.56	.071	.050	67.82	15.91	1.24	0.36	7.7
B_2	2.78	4.19	.069	.033	61.22	15.43	4.03	5.04	8.0
C_1	2.00	3.53	.040	.041	54.94	12.63	7.63	10.96	8.1

Profile No. 3

Located near St. Walburg. Podzolised light loam on glacial till. Undulating upland topography, with heavy stand of aspen. Lower land is either muskeg with spruce and various shrubs, or low sand ridges with jackpine vegetation.

A_0	0 – 2″	Black raw humus layer.
A_1	2 – 2½″	Dark gray fine sandy loam, structureless. Mineral soil high in humus.
A_2	2½ – 7½″	Ashy gray light loam (silty). Powdery structureless layer.
B_1	7½ – 13″	Dark gray-brown clay. Compact, coarse granular structure.
B_2	13 – 36″	Dark gray clay with small stones. Compact, breaking into coarse granules.
C_1	36″+	Dark gray clay, granular, calcareous.

Chemical Analysis of Profile No. 3.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	5.34	32.80	1.55	.114	54.23	6.00	2.19	—	7.3
A_1	1.22	4.90	.186	.031	82.82	8.31	0.91	—	7.3
A_2	0.62	1.21	.030	.012	84.91	8.64	0.70	0	6.9
B_1	1.90	3.02	.050	.018	79.06	14.46	0.75	0	6.5
B_2	1.85	4.66	.037	.023	79.85	14.34	0.75	0	6.5
C_1	1.24	6.57	.024	.038	76.68	11.13	3.09	3.85	7.8

Discussion of Profiles 1, 2, and 3

The data for Profiles Nos. 1, 2 and 3 illustrate the more important characters of podzolic upland soils developed on glacial till deposits, the most extensive soils of the gray soil zone. The profiles exhibit the following morphological features: a surface layer of partially decomposed organic matter, except where destroyed by forest fires; a dark gray, platy A_1 horizon, which is usually very thin, and is sometimes absent; a strongly leached, ashy gray, A_2 horizon, often platy but easily crushed to a powdery form; the heavier B_1 and B_2 horizons, coffee brown to grayish brown in colour, compact, and breaking into angular fragments or coarse granules; and finally a lighter coloured highly calcareous parent material. The zone of lime carbonate frequently extends into the B horizons.

Mechanical Analysis of Profile No. 3

Horizon	Clay (<.005 mm.)	Silt (.005-.05)	Sand (.05-1.0)
A_1	12.75	36.15	44.48
A_2	15.00	45.25	35.89
B_1	41.25	19.50	40.14
B_2	41.60	19.00	40.06
C_1	33.70	22.45	41.96

The analytical results indicate that these soils have been subjected to the leaching processes associated with podzolic weathering. In all cases the B horizons are higher in total oxides and lower in silica than the corresponding A_1 and A_2 horizons. The calcium content is high in the A_0 and A_1 horizons, lowest in the A_2, and thereafter increases with depth. High amounts of lime carbonate ($CaCO_3$) are frequently found in the lower B horizons, as shown by the figures for CO_2. No free lime was found in any of the A_2 horizons.

The organic nature of the surface layer is indicated by the figures for nitrogen and loss on ignition, which are considerably higher in the A_0 than in the lower horizons. The content of nitrogen is higher in the B_1 than in the A_2 which, with figures of a similar order for hygroscopic moisture and loss on ignition, indicate a movement from the A_2 to the B horizons of both organic and inorganic colloids. The nitrogen content drops sharply in the parent material.

Phosphorus, like nitrogen, is found in greatest amounts in those horizons relatively high in organic matter, except in the parent material, where the phosphorus content is generally higher than that of the lower B horizon.

The pH values indicate that these profiles are slightly acidic to quite alkaline in reaction. The lowest pH values occur in the A_2 and B horizons, and the latter are generally the most acid, unless lime carbonate is present. No serious acidity however, has so far been encountered in the podzolic glacial soils.

The mechanical analysis of Profile No. 3 illustrates the great textural difference between the A and B horizons. A comparison of the clay and silt contents of these horizons suggests that a mechanical downward movement of some of the fine clay fraction has taken place. This is in accord with the chemical data for silica and sesquioxides, and also with the textural properties these soils exhibit in the field.

The foregoing analyses indicate that only slight differences in composition exist between the B_1 and B_2 horizons. The latter are characterized by lower nitrogen and higher pH values than the former, and frequently contain lime carbonate.

Profile No. 4

Located east of Fort a La Corne Forest Reserve. Podzolised fine to very fine sand of alluvial origin, on level well drained land. Aspen and jackpine vegetation.

A_1	0 – 1″	Gray, with faint dark tinge. Fine sand with fairly high humus content, loose and structureless.
A_2	1 – 13″	Gray, fine and very fine sand, loose and structureless.
B_1	13 – 36″	Brown light fine sandy loam, dusted with gray. Hard and compact, nutty to cloddy structure.
B_2	36 – 58″	Gray brown very fine sandy loam. Moderately compact but not as hard as B_1.
C_1	60″+	Yellowish gray fine and very fine sand. Loose and structureless. No lime carbonate present.

Partial Analysis of Profile No. 4.

Horizon	pH	H_2O	Loss on ignition	Clay < .005 mm.	Silt .005–.05 mm.	Sand .05–1.0 mm.
A_1	6.8	0.82	4.73	6.15	6.85	85.48
A_2	6.0	0.45	2.03	6.10	4.70	87.78
B_1	6.4	0.83	1.94	11.50	2.25	85.00
B_2	5.4	1.39	3.16	19.90	1.95	77.90
C_1	5.6	0.55	1.03	7.55	4.50	89.00

Profile No. 4 represents the finer textured podzolic sands, as shown by the compact, cloddy structure and relatively heavy texture of the B horizons. In the coarser sandy and gravelly types these horizons are but faintly compacted and the profile shows little textural variation.

In accordance with the sandy nature of the parent material and the absence of lime carbonate, Profile No. 4 has been leached more deeply and is more acid in reaction than the podzolic glacial soils. These conditions are indicated by the depth of the A_2 and B horizons, the low pH values, particularly in the lower horizons and the figures for mechanical analysis. The latter indicate a decided downward movement of clay, the B horizons containing between two and three times as much clay as the A_1 and the A_2. It should be noted however that the total amount of colloidal material removed from the A horizons is much less than in the case of the heavier textured podzolic soils. Thus while Profile No. 4 is deeply leached as compared with the heavier types, the severity of leaching is not outstanding in view of the ease of water percolation through sandy soils. Similarly the low pH values are readily accounted for by the low lime content of the sands, such soils frequently exhibiting slight acidity even under semi-arid steppe conditions. A relatively much greater leaching effect is necessary to remove the carbonates from the upper two feet of a highly calcareous loam such as Profile No. 1.

Profile No. 5

Located near White Fox. Peat podzolic very fine sandy loam on alluvial deposits of level topography. Present cover thin grass and small clumps of willows, the original cover of sphagnum peat and spruce having been largely destroyed by fire.

A_0	1 – 2″	Black humus layer, grass vegetation on burnt-over peat.
A_1	2 – 4″	Very dark gray very fine sandy loam, thick platy structure, easily crushed.
A_2	4 – 8″	Dark gray with brown tinge, very fine sand, structureless.
B	8 – 10″	Brownish gray loam (silty), streaks of ferric oxide; granular structure.
	10 – 16″	Rusty gray heavy loam, spots of ferric oxide, slightly platy.
	16 – 21″	Yellow brown very fine sand; structureless.
	21 – 25″	Blue gray to yellow heavy loam, compact, coarse granular.
	25 – 46″	Yellow gray very fine sandy loam, granular; slighlty calcareous.
C_1	46 – 56″+	Light gray very fine sandy loam, structureless; calcareous.

Chemical Analysis of Profile No. 5.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	4.28	20.37	.827	.081	60.68	9.29	1.84	—	7.6
A_1	1.00	2.82	.074	.029	80.45	10.52	0.84	—	7.5
A_2	1.00	2.52	.060	.027	80.52	10.10	0.92	—	7.4
B	2.12	2.49	.099	.078	76.47	14.04	0.85	—	7.2
	2.38	2.74	.049	.053	76.16	15.42	0.88	—	7.1
	1.51	1.79	.031	.050	79.55	13.41	0.97	—	7.4
	2.50	2.80	.043	.047	74.85	15.51	1.01	0	7.4
	1.50	2.80	.034	.053	78.05	14.58	1.12	0.29	7.4
C_1	1.30	2.10	.025	.046	71.01	11.60	3.84	4.10	8.2

Profile No. 5 represents a podzolic peat soil modified by recent fires. The original peat cover of between 8 and 12 inches was observed in a nearby clump of spruce trees which had escaped the fire. The upper horizons of the present profile are similar to those of the degraded black sandy soils, the A_1 being well defined and the A_2 being dark gray brown rather than

ashy gray. The lower horizons differ considerably from those of the upland podzolic soils, the mottled colouring, presence of ferric oxide and successive layers of variable textured materials being typical of the poorly drained subsoils of sandy peat depressions.

The chemical analysis supports the morphological data, the relative contents of silica and total oxides in the upper horizons being typical of podzolic soils. In the lower horizons these constituents vary with textural conditions, higher silica and lower sesquioxides accompanying lighter textures. Both nitrogen and phosphorus values show a decided increase in the upper B as compared with the A_2 horizon. The pH values for this profile are surprisingly high, particularly since the carbonates have been completely removed to a depth of two feet, with only moderate amounts present four feet below the surface.

Profile No. 6

Located north of Tisdale. Degraded heavy clay loam (silty), on heavy lacustrine deposits. Undulating upland topography, under a heavy stand of aspen and balsam poplar.

A_0	0 – 2″	Black raw humus layer.
A_1	2 – 7″	Dark gray heavy clay loam (silty), coarse granular structure.
A_2	7 – 11″	Gray-brownish clay loam (silty). Thick platy, crushing to fine granules.
B_1	11 – 24″	Dark gray heavy clay. Compact, breaking into coarse granules.
B_2	24″+	Grayish-white heavy clay. Compact and calcareous.

Chemical Analysis of Profile No. 6.

Horizon	H_2O	Loss on ignition	N.	P.	SiO_2	R_2O_3	Ca	CO_2	pH
A_0	6.50	30.11	1.060	.106	50.13	13.56	1.48	—	6.9
A_1	6.30	6.42	.254	.052	66.74	19.34	1.04	—	6.6
A_2	2.85	3.00	.115	.026	76.54	13.81	0.93	—	6.9
B_1	4.78	5.32	.084	.029	64.50	24.00	0.76	0	7.5
B_2	5.10	5.21	.077	.055	58.01	22.88	2.98	3.14	8.1

The degraded black soils include a variety of profiles ranging between black and podzolic gray types. Profile No. 6 represents a fairly advanced stage of degradation, but the data given above do not indicate full podzolic development. Compared with the first four profiles the Tisdale soil is characterised by a relatively deep A_1 horizon, high in organic matter and nitrogen, while the A_2 horizon is grayish brown instead of ashy gray. The nitrogen content is higher throughout and decreases with depth as in the normal grassland soils. Nevertheless the great difference in silica and sesquioxide contents between the A_2 and B_1 horizons indicates considerable leaching. This is confirmed by the figures for

Mechanical Analyss of Profile No. 6.

Horizon	Clay (<.005 mm.)	Silt (.005–.05 mm.)	Sand (.05–1.0 mm.)
A_1	29.22	41.7	25.42
A_2	28.25	40.25	27.85
B_1	74.35	19.10	6.13
B_2	80.95	17.00	3.63

mechanical analysis, which indicate a very decided downward movement of clay. As in the case of the St. Walburg profile (No. 3) there is a relatively high silt content in the A horizons. It is believed that the heavy texture of the soil and the comparatively recent invasion of the forest cover have prevented the leaching of the degraded soils from proceeding as deeply as in the case of the podzolic glacial and sandy alluvial types. Agriculturally the degraded black soils are more productive than the gray soils.

Profile No. 7

Located west of Nipawin. Podzolic silty loam on heavy lacustrine deposits. Nearly level topography, well drained. Heavy aspen cover. Peat in adjoining low areas.

A_2	0 – 12″	Gray with brown tinge. Loam, silty, with large platy structure, breaking easily to flat nut-like forms and large granules. A_0 and A_1 horizons not present.
B_1	12 – 15″	Brown to grayish brown light clay. Small clod structure, breaking to hard angular coarse granules. A hard compact horizon.
B_2	15 – 42″	Bright yellow brown clay loam. Somewhat larger clods, but less compact than B_1, and with small pores.
C_1	42 – 50″	Gray with slight brown tinge. Heavy clay (silty), coarse granular structure, highly calcareous.

Partial Analysis of Profile No. 7.

Horizon	pH	H_2O	Loss on ignition	Clay (·005 mm)	Silt (·005-05)	Sand (·05-1·0)
A_2	6.9	1.29	4.33	16.35	42.40	39.10
B_1	6.4	1.96	4.68	28.95	35.65	29.90
B_2	6.8	1.58	2.97	24.55	35.55	40.00
C_1	7.6	2.49	5.64	52.50	35.65	10.86

Profile No. 7 represents a more advanced stage of podzolic leaching on heavy lacustrine soils as compared with Profile No. 6. The somewhat lighter textured parent material of No. 7 may have permitted better percolation of soil water. The more strongly leached condition of this profile is shown by the absence of the A_1 horizon and the greater thickness of the A_2 and B horizons. The lower pH values and the greater depth of the lime layer are also significant. The mechanical analysis indicates a removal of clay and a relative increase of silt for the A_2 horizon, a condition found in the other profiles under discussion.

Profile No. 8

Saskatchewan river, north of Nipawin. Peat profile from muskeg. Taken on long gentle slope above river bank. Tamarack, alder and Labrador tea vegetation. Frozen subsoil layer below 12 inches at time of sampling (June 12).

Surface—Light yellow-brown fresh sphagnum moss.

0 – 10″	Yellow brown raw sphagnum and brown decomposing peat.
10 – 12″	Dark brown decomposing peat, with woody fragments of stems, roots, etc.
12″+	Frozen layer, very dark brown mucky peat, more granular than above, and with fewer woody fragments.

Profile No. 8 represents an acid sphagnum peat under a cover of tamarack trees. The frozen condition of the peat below 12 inches prevented deeper sampling. The profile above the frozen layer was saturated with water. The surface layer of fresh sphagnum is quite acid, but the deeper horizons exhibit only slight acidity. The organic nature of the profile is illustrated by the high values for hygroscopic moisture and loss on ignition.

PARTIAL ANALYSIS OF PROFILE NO. 8.

Depth	pH	H_2O	Loss on ignition
Surface	5.4	—	—
0 – 10″	6.8	11.63	97.14
10 – 12″	6.9	17.20	91.81
12″ plus	6.6	17.50	76.00

The high lime peats are composed of coarser materials developed largely from sedges. These soils are often slightly calcareous at the surface, highly calcareous below and are underlain by calcareous sand and sandy clay deposits.

DISCUSSION

The podzolic nature of Saskatchewan wooded soils is discussed in a number of papers by Joel (4, 5) and in the latest soil survey report (13). The present study shows that the wooded soils exhibit considerable variation in morphology and composition. The variations represent different degrees of podzolic leaching, and the main profile features indicate that podzolization has been the dominant factor in the development of the wooded soils.

These Saskatchewan soils are generally similar to the wooded soils of Alberta. Many of the latter however have developed under a heavier precipitation and are more severely leached. The lime carbonate layer occurs at a depth of four feet or more below the surface, while the pH values and calcium contents are lower than those reported in this study (12). Wooded soils with shallower profiles are encountered in the more northerly portion of Alberta, where the rainfall is lower (14). It is of interest to note that the gray wooded soil zones of Alberta and Saskatchewan, including the Pre-Cambrian region, have a combined area of over 300,000 square miles. Large areas of wooded soils also occur in Manitoba (1). The podzol soils found in other parts of the world are discussed in the works of Glinka (3), Marbut (9) Robinson (11) Joffe (6) and Kellog (7), and these were consulted in making the following comparisons.

The Saskatchewan podzolic soils possess a number of features which differentiate them from the podzol soils of more humid regions. These features are: highly calcareous parent materials, frequent presence of calcium carbonate within the solum, relatively high pH values, and very slight unsaturation, the base exchange complex being dominated by calcium (10). From the above conditions it is evident that these soils are not true podzols according to the prevailing systems of soil classification.

On the other hand Saskatchewan wooded soils exhibit many characteristics common to the true podzol. In the first place it should be remembered that the term "podzol" has been adopted from the Russian school of soil science, where it denoted a morphological feature of certain soils. Glinka states "This term is used to designate soils which have a pronounced and well developed whitish A_2 horizon." (3, page 48). This description fits many of the Saskatchewan podzolic soils.

A study of profiles 1 to 5 presents further evidence of the true podzol state of these soils, as shown by the impoverishment of the A_2 in respect to bases, sesquioxides and organic matter, with a corresponding increase of these constituents in the B horizons. Conversely the A_2 is higher in silica than the B. The low content of calcium in the A_1 and A_2, and the high content of sesquioxides in the B, as compared with the C horizon, are also features of the true podzol (6). The presence of two B horizons of essentially similar composition, which according to Joffe (6) is evidence of podzolic maturity, has already been discussed in the data for profiles 1 and 3. Base exchange studies of these soils, made by Mitchell and Riecken (10) indicate that while there is little or no unsaturation, the total exchange capacity varies throughout the profile in a manner similar to that of the true podzols (6).

While the Saskatchewan wooded soils studied to date are found under a mixed forest cover, the dominant vegetation consists of poplars (*P. tremeloides* and *balsamifera*). Furthermore, with the exception of the jackpine sands, the more strongly developed podzolic profiles are also associated with the poplar cover. Where spruce trees predominate the soil is usually of a peaty nature or presents features of a poorly drained podzolic type. It is not known if this present vegetative cover is typical of former conditions. Leahey (8) in his study of Alberta wooded soils found evidence in support of the spruce as the climax type of vegetation, despite the present dominance of the poplar. It is possible that a similar condition obtains in Saskatchewan, but no ecological data are available on this question.

Theoretically the Saskatchewan podzolic soils should have developed under conditions of much greater acidity and higher base unsaturation, and probably in association with a coniferous forest. From this viewpoint these soils must now be undergoing a process of regradation, following the replacement of conifers by the poplar. This theory however does not explain how the poplar became established on the original highly acid soil. As already stated, at the present time the moderately acid podzolic sands are largely covered by jackpine (*Pinus Banksiana*). The black and degraded black sands whose reaction is nearly neutral are dominated by poplar vegetation.

In contrast to the above theoretical considerations there is definite evidence that podzolic profiles have developed under poplar trees in southern Saskatchewan. In the black soils zone and even in the semi-arid dark brown soils there are small clumps of poplar and willow trees, locally known as "bluffs". Where these bluffs surround low moist depressions, they are frequently underlain by podzolic soils with somewhat poorly drained subsoils (13). These soils must have developed under their present cover, as the previous existence of coniferous "bluffs" in a semi-arid grassland region cannot be regarded as even a remote possibility. In addition to the "bluff" podzols the black soil zone contains extensive islands of upland podzolic and degraded black soils under poplar vegetation, situated in areas entirely devoid of coniferous trees. Glassey (2) reported podzolic soils under aspen vegetation in brown, dark brown and chernozem soils of Wyoming.

From the foregoing discussion it is evident that the wooded soils of Saskatchewan do not fit satisfactorily into any of the great soil groups of

the world, as the latter are now defined. Leahey (8) concluded that the presence of calcium carbonate in Alberta wooded soils was not a sufficient reason for excluding them from the podzol group. The data presented in this study justify a similar conclusion regarding the wooded soils of Saskatchewan. They may be regarded as a distinct branch of the podzol family, possessing certain definite characters of their own. This study also suggests that while conditions of strong acidity and high base unsaturation are associated with podzol soils of humid regions, it seems evident that a considerable degree of podzolization may take place under the conditions of slight acidity and relatively low precipitation found in Saskatchewan.

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RELATIONSHIPS BETWEEN SOIL MICRO-ORGANISMS AND SOIL-BORNE PLANT PATHOGENS. A REVIEW[1]

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INTRODUCTION

Despite the extensive amount of work conducted on many phases of soil bacteriology, comparatively little is known regarding the interrelationships of the various groups of soil organisms. The complexity of the soil population renders it impracticable, at the present state of knowledge, for these relationships to be studied as a whole, so that it is possible only to isolate and examine the reactions between certain specific groups. It is the purpose of this article to consider specially the work done on the possible relationships of soil saprophytes to organisms producing disease in plants.

It is not intended to review associative and antagonistic relationships of organisms in general. Not only has a very extensive literature been accumulated concerning the favourable and unfavourable effects of micro-organisms one upon another, but a comprehensive historical review of antagonistic relationships has been compiled by Waksman (98), while more recently the subject of competition among fungi has been reviewed by Porter and Carter (72). Other recent reviews on subjects which bear some relation to that under consideration are those by Katznelson (50) on bacteriophage in relation to plant disease, and by Garrett (33) on soil conditions as affecting root-infecting fungi.

MISCELLANEOUS INVESTIGATIONS

One of the earliest studies in microbiological control of plant disease is that of Potter (73), who, in 1908, attempted to control bacterial disease by using toxins, rather than through the actual antagonism of one organism to another. He found that *Pseudomonas destructans*, cause of rot of turnip, produced a potent, heat-resistant toxin. In the presence of the toxin the bacteria failed to grow, and microscopical examination revealed the complete killing of the organisms. He continued the experiment by spraying turnips with the toxins, and produced remarkable effects in checking the disease. The toxin was more or less specific for the organism that produced it and had no effect on species of *Penicillia*, *B. subtilis*, or *Proteus vulgaris*. He conducted much the same experiment with *Penicillium italicum* on oranges to find that the resultant toxin checked the disease entirely. Little attempt was made to determine the nature of the toxin. In studying the persistance of the citrus-canker organism *Pseudomonas Citri* in soil, Fulton (30) noted that certain bacteria commonly found in soils had a marked deleterious effect on the pathogen in artificial culture media, both by inhibiting growth and by killing. The author suggested this in

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explaining the rapid decline of *P. Citri* in unsterilized soil. In 1921 Hartley (37) found that the inoculation of steamed soil with various saprophytic forms resulted in a decrease of the parasitic activity of *Pythium deBaryanum* upon forest nursery seedlings.

Porter (70), working with various species of fungi, determined their characteristics as exhibited by their growth in the presence of other fungi. Chiefly interested in antagonism, he distinguished five different types of inhibition. Of practical interest were his experiments with wheat and flax seedlings. He showed that wheat seedlings were measurably protected from *Helminthosporium* sp. by using a certain isolated strain of bacteria which proved antagonistic to the pathogen. Flax seedlings were also protected in the same way from *Fusarium* sp. He attributed the prevention of injurious action by the pathogen to a direct repressing action by the bacteria. Later, the same author (71), studying the effect of mixed cultures of bacteria and fungi, found pronounced inhibitory effects of certain bacteria common to soil, *e.g. B. mesentericus vulgatus*, on various cultures of fungi.

In 1926, Sanford (81) working with *Actinomyces scabies*, cause of potato scab, found that this pathogen was very sensitive to secreted products of moulds and bacteria. *A. scabies* has been shown to prefer alkaline conditions. When grown in close proximity to *Ps. fluorescens*, *B. mycoides*, *B. cereus*, *B. vulgaris*, *B. Megatherium*, and *B. mesentericus*, the acid producing qualities of these organisms inhibited *A. scabies* to a considerable degree. However, the investigator does not attribute the complete inhibition of *A. scabies* to acid reaction, since he isolated a strain of bacteria from the soil which definitely inhibited the pathogen by means other than acidity. He showed that potato scab could be reduced by plowing under a green rye crop, and explained the action as probably owing to the antibiotic qualities of certain predominant soil micro-organisms, especially saprophytic actinomycetes. He tentatively suggests that the cause of toxicity is associated with competition for food, and with an unfavorable substrate reaction.

Millard and Taylor (64) also studied *Actinomyces scabies* in relation to green manures and the action of other organisms. Soils, with and without cut grass, were inoculated with varying proportions of *A. scabies* and *A. praecox*, the latter a saprophytic form. A marked reduction of scab was noted with inoculation of *A. praecox* depending upon the relative abundance of the actinomycetes. Green manuring alone did not control scab. The authors concluded that the inhibiting effect of the saprophyte on *A. scabies* was not due to change of reaction, but probably caused by a starving out of the weaker organism in competition for available food. Goss (34) found severity of scab to be dependent on the amount of inoculum *(A. scabies)* in the soil which in turn is believed to be conditioned in part by the influence of the soil microflora on the pathogen. Tests of the antagonistic effect of *A. praecox* failed to confirm the findings of Millard and Taylor. No evidence was obtained as to whether the effect of the soil flora on *A. scabies* was due to specific organisms, related groups of organisms, or simply to numbers of competing organisms.

Associations of plant pathogens with each other and with saprophytic organisms were recorded by Machacek (62) in studying rots in fruits and

vegetables. The nature of the association and other factors, such as temperature, sequence of infection, and relative amounts of inoculum may modify symptoms of the disease in the host. The writer points to the difficulty of emulating field conditions in the laboratory where the association may vary from that on the host.

Rosen and Shaw (79), working in 1929 with *Sclerotium Rolfsii*, produced some interesting results with special reference to metabolic interchanges between soil inhabitants. The authors showed that when *S. Rolfsii* and *Fusarium vasinfectum* are grown together the reaction is a very important factor. When acid conditions below pH 6.9 prevailed, *S. Rolfsii* outgrew and covered the *Fusarium* sp. At a pH above this, the reverse prevailed. In the same year Lewis (60) studied the effects of soil toxins, which will be referred to later. He found that fungi in general were more resistant to these toxins than were bacteria. Bamberg (2) in 1930 isolated certain cultures of bacteria from corn plants that prevented normal infection by *Usilago Zeae*, and were capable of destroying colonies of the smut fungi on culture media. When inoculated with the pathogen, only incipient galls were formed. The bacteria were capable also of destroying the galls after they were formed. He found also that the isolated strains of bacteria inhibited colonies of *U. Avenae*, *U. levis*, *Tilletia Tritici*, and others. He showed, moreover, that the filtrates were useless, the organisms themselves being necessary. Other isolated organisms had no inhibitive effect whatever. It is suggested that wide distribution of such bacteria might bring about a check of the multiplication of such fungi in the soil. The antibiotic action of bacteria to smut and other fungi was further studied by Johnson (48) in 1931, who isolated four types of bacteria antibiotic to certain fungi. She isolated a coccus, a motile non-sporulating rod, a motile sporulating rod and a mycobacterium. The author suggests that the solvent action on the cell walls of the sporidia was due to bacterial enzymes. Other bacteria possess antibiotic action toward fungi attributed to some factor or principle not enzymatic in nature.

The effects of mixtures of micro-organisms on the severity of plant diseases have been studied extensively by Fawcett (26, 27) and co-workers (28, 84), and also by Vasudeva (93). These studies have been concerned more particularly with associations of micro-organisms within the living host plant rather than with associative or antagonistic action in the soil between soil forms and soil-borne pathogens. The findings of these workers are of interest due to the possibility that certain species found to modify the course of the disease when mixed with parasitic forms may exist as saprophytes in the soil.

Extensive studies on antagonisms between pathogenic fungi and a variety of other micro-organisms including bacteria, actinomycetes, and fungi have been reported by Endo (24). Experiments with *Hypochnus centrifugus*, *H. Sasakii*, *and Sclerotium Oryzae-sativae* showed that many organisms of the above groups, including forms occurring in soil, exerted highly antagonistic effects on the development of the pathogenic types.

ROOT-ROT INVESTIGATIONS

The possible actions of soil micro-organisms toward plant pathogens have received particular attention with regard to their antagonistic relationships to the various root-rot fungi. Some promising work has been con-

ducted by various workers whose results have opened up new avenues of research on the difficult problem of controlling these various diseases.

Sanford and Broadfoot (83), in 1931, studied the effect of soil inhabiting organisms on the virulence of *Ophiobolus graminis*, cause of take-all of cereals. Bacterial and fungal cultures were isolated from soil and culms of wheat, and filtrates obtained after growth on artificial culture media. Combinations of filtrates and pathogen, and cultures and pathogen were applied directly over the seed and covered with earth. Twenty-six fungal and 40 bacterial cultures were used. According to the results, the organisms used fell into various classes, according to the percentage control of disease obtained, the percentage varying from nothing to almost complete control. A few of the cultures increased the severity of the disease as much as 10%. Unlike Bamberg (2), who found filtrates useless on smut fungi, these workers found that they were effective, but not nearly so much so as the cultures themselves. At no time did the saprophytic cultures of filtrates affect the vigour of the plants. These results showed definitely that certain fungi, actinomycetes and bacterial species are effective in suppressing the pathogenicity of *O. graminis*.

The work of Sanford and Broadfoot found confirmation in experiments reported by Moritz (65) in 1932. In comparative pot culture tests with sterilized and unsterilized soil, the severity of infection of wheat by *O. graminis* was found to be much reduced by unsterilized soil, the protective action of which was attributed to the "inoculum" effect. This protective action varied with the soil type, being greatest in soils showing the lowest incidence of the disease. The author believes that the antagonistic effect is of quantitative rather than qualitative nature and is related to the microbiological activity of the soil.

Henry (39), in 1931, studied the natural microflora of the soil in relation to the foot-rot problem of wheat. It was found that the natural microflora had a marked inhibitive action on the growth of *Helminthosporium sativum* in soil with indication of a similar effect on *Fusarium graminearum*. Bacteria, fungi, and actinomycetes isolated from the soil all showed a suppressive action, most evident with fungi. A combination of all types proved the most effective. It was also shown by Henry (40) that though *H. sativum* will sporulate readily in certain sterilized soils, it will not if they are not sterilized. The fact that soils capable of supporting sporulation of this fungus may be rendered ineffective by adding small amounts of unsterilized soil suggests that sporulation is inhibited by saprophytic soil micro-organisms. It is suggested that the fact that root-rot diseases of wheat are less severe when the crop is grown on summer-fallowed land than on land cropped to wheat several years is related to the growth of soil saprophytes, which in bare fallow have an advantage over the pathogens in competition for food.

Studies were also made by Henry (41) on the influence of temperature and soil sterilization on the protective value of unsterilized soil against infection of wheat by *Ophiobolus graminis*. He found that whereas at 27° C. protective action of unsterilized soil was evident, it was not apparent at 13° C., blighting of seedlings being equally severe in sterilized and unsterilized soil. The work of Garrett (31, 32) gives support to Henry's

findings. Garrett points out that *O. graminis* may alternate between parasite and saprophyte and in the latter stage may be susceptible to the antagonistic action of various soil organisms, a condition favoured by summer-fallow. Garrett (32) puts forth the hypothesis that the rate of growth of the pathogen along the roots is related to the concentration of carbon dioxide in the root zone. Carbon dioxide is produced by respiration of the host root, the fungus hyphae, and the soil microflora. As is known, the latter is particularly abundant in the rhizosphere.

Broadfoot (7), working with cultures of bacteria and fungi used in previous experiments of Sanford and Broadfoot (83), studied their antagonistic and compatible growth relationships towards *Ophiobolus graminis* on various culture media. He found that many of the organisms which exercised a marked degree of control on *O. graminis* on wheat in soil were not antagonistic in culture media, and many of those exhibiting no effect were antagonistic in culture. This study demonstrates that the growth reactions of various organisms and *O. graminis* associated on artificial culture media is not a reliable indication that the same organisms will or will not suppress the virulence of the pathogen on wheat in soil or open pot culture.

Brömmelhues (8), also working with *O. graminis*, presents a somewhat different view. She found that the pathogen was inhibited strongly in culture media by *Helminthosporium sativum* and *Penicillium* sp. Comparative soil tests were conducted to determine the effects of *H. sativum*, *Cladosporium*, *Mucor*, *Alternaria*, and *Penicillium* species on *O. graminis* attacking wheat. It was found that the damage from the pathogen was greater when the other fungi had a start of four weeks. It was thought the growth of the previously inoculated fungi damaged the roots, and thus increased the susceptibility of the wheat to attack by *O. graminis*. The author maintains that the weakening by other fungi is of greater consequence than any antagonism between the pathogen and fungi. When simultaneous inoculations with *Cladosporium*, *Alternaria*, and *Mucor* were made, damage to the wheat plants was greater than with single inoculation. In the case of *H. sativum* and *Penicillium* sp., the two which exerted greater influence on agar plates, combined action gave less damage than caused by *O. graminis* alone.

Greaney and Machacek (35) investigated the influence of the saprophytic fungus *Cephalothecium roseum* on *Helminthosporium sativum*, pathogenic to wheat, and noted a suppression of pathogenicity by antagonistic action of the former. Pot-culture experiments demonstrated a measure of biological control by *C. roseum* over *H. sativum*.

Root rots of other hosts have also undergone investigation. In 1932, Tims (91) discovered actinomycetes antagonistic to a *Pythium* root parasite of sugar cane. He isolated them from sugar cane soils and later applied them to sterilized soils inoculated with a *Pythium* sp. under greenhouse conditions. He found that the saprophytic actinomycetes reduced the amount of root rotting in young cane and corn plants, and when grown in culture produced a toxic principle.

Recent work by Rand and Dopp (75) with *Pythium* root rot of sugar cane would suggest that soils of low biological activity, combined with lack of aeration and drainage, may accumulate various injurious products.

These increase the susceptibility of sugar cane to *Pythium*. Improving the general level of fertility, by increasing the biological activity of decomposing and nitrifying organisms with suitable drainage and aeration, markedly increased the yields in subsequent experiments. Drechsler (22) quite recently has discovered two Hyphomycetes capable of parasitizing the oospores of many species of *Pythium*. Infection is accomplished by perforation successively of oogonial and oospore walls followed by the development of haustoria which appropriate the protoplasmic contents. The author suggests that on account of its widespread destruction of oospores, *Dactylella spermatophaga*, one of the Hyphomycetes referred to, probably serves as an effective agent in promoting soil sanitation over extended periods of time.

In 1929 Fellows (29) in studying certain soil phases of the wheat "take-all" problem, found that the application of horse and chicken manure, alfalfa stems, boiled barley and oat mixtures, and potato flour, both in greenhouse and field, reduced the severity of the disease. Working on the assumption that manure increases the numbers and activities of common competitive organisms which inhibit the growth of root-rot fungi, King, Hope, and Eaton (51) applied varying amounts of manure to different soils and studied their microbiological activities. The authors came to the conclusion that manured soils contained a larger population of cocci, rods, actinomycetes, and fungi than unmanured soils. In tests with *Phymatotrichum omnivorum*, cause of cotton root rot, they found that this pathogen existed in greater numbers in the unmanured soils. They showed that manuring definitely controls the root rot, and suggested parasitism by bacteria on the fungal strands as one of the reasons for the decline of the pathogen in the manured soils.

Of interest is the adaptation by these workers of the Cholodny (13) slide method for studying the root-rot fungus and its inter-relations with other organisms, as described more in detail by Eaton and King (23). The value of microscopical methods has also been shown by Hildebrand and Koch (42). In studying strawberry and tobacco seedlings these workers developed a procedure for the direct study of root systems which proved to be of aid in noting the sequence of infection by organisms involved in the root-rot complex.

Previous to the work of King, Hope, and Eaton, there had been experiments conducted in Texas and Arizona on the control of cotton root rot by various investigators, with somewhat conflicting results. Scofield (85) and Taubenhaus and Killough (88), experimenting with manuring infected soils for varying lengths of time, did not obtain good results, and maintained that in Texas it was doubtful if the addition of humus and manure to the soil would greatly influence root-rot control. The addition of manure, however was tried in Arizona by King and Loomis (52) with better results. Manure and organic materials applied to infected soils consistently showed a reduction in the affected area, and by recording the progressive damage of the disease at different intervals during its activity, it was found that the incidence of the disease was delayed in manured areas. No theory as to why this should take place was advanced by the authors at that time. Later the same workers (53) experimented further on cotton root-rot control. They applied organic materials and manure

in furrows to alternate quarter-acre plots continually cropped to cotton for several years. This method showed effective treatment in reducing the extent of infection and in delaying the disease. Manured plots seemed effective barriers in restricting or retarding the advance of the mycelium from adjacent untreated areas.

Recent work by Drechsler (20, 22) has shown that putrefactive bacteria in large numbers have an inhibitive and antagonistic action toward *Pythium* and *Phytophthora* species. Of possible interest in this connection are the observations of Neal, Webster, and Gunn (66) who showed that ammonia has a definite toxic effect on the cotton root-rot fungus, *Phymatotrichum omnivorum.*

McNamara (63), studying the behavior of cotton root rot in Texas, experimented with clean fallows. These experiments were conducted on the theory of the possibility of starving the root-rot organism by preventing growth of all vegetation. Clean fallows were tried on two plots of land where most of the plants had previously died from the disease. The author maintains that this preliminary experiment gave good results, with a measure of control which justified further experimentation. Summer-fallowing as a means of controlling certain diseases has been tried by other authors on other diseases with varying results. Sanford (82) states that summer-fallow reduces definitely *H. sativum* and *O. graminis* but that definite proof of the method of reduction is lacking. It may be that antagonistic effects of other organisms, change of conditions inimical to the pathogen, or summer-fallowing result in lack of food for the pathogen.

In 1929, King and Loomis (54) conducting further studies on cotton root rot, described a sclerotium stage of the fungus. During their investigations on artificial culture media, they noted that the presence of secondary organisms in cultures of *Phymatotrichum omnivorum* retarded considerably the growth of the mycelium, and checked it completely in some cases. Chief among these contaminants was an organism resembling *Fusarium.* Other fungi and bacteria also showed varying degrees of inhibition. It is commonly observed that root-rot injuries are followed by the appearance of secondary saprophytes not capable of entering living host plants, but whose activities may hinder the immediate return of the root-rot fungus, or discourage retrogressive movements of the mycelial strands. The authors suggest that under natural conditions the effects of such secondary saprophytes found in the soil upon the fungus of root rot may play some part in determining the distribution of the disease.

In this review it is not intended to discuss pathological aspects of root-rot diseases, nor factors associated with purely chemical and physical properties of soil which modify the action of pathogenic organisms. This latter phase of the problem has been recently reviewed by Garrett (33). It should be pointed out, however, that any clear-cut distinction between the physico-chemical and soil microbiological factors is impossible. It is therefore probable that even where microbial associations or antagonisms have not yet been demonstrated, they have been effective in many cases where chemical or physical modifications of the soil have altered the pathogenicity of root-invading fungi.

INHIBITIVE ACTION OF TRICHODERMA, ETC.

A number of investigators have found that certain species of *Trichoderma* have a noticeably inhibitive action on plant pathogens. Chief among these species is *Trichoderma lignorum*, with which considerable experimentation has been conducted. Weindling (94) in 1932, when investigating the damping-off of citrus seedlings, found *T. lignorum* parasitizing such fungi as *R. Solani*, *P. parasitica*, *Pythium* sp., *Rhizopus* sp., and *S. Rolfsii*. Later (96) working on the inhibitive effect of *T. lignorum* on *Rhizoctonia*, he found that *Trichoderma* spores added to acid sterilized soils prevented damping-off of citrus seedlings. He also found that *Trichoderma Koningi* and *Trichoderma album* attacked *Rhizoctonia*. Again, the same author (95) found that other fungi were capable of parasitizing *R. Solani* in the same manner as the *Trichoderma* species.

Brown (9) working with the Texas root rot of water melons, describes the manner in which water melons are invaded by the mycelium of *Phymatotrichum omnivorum*. By adding various mixtures of cultures of certain fungi and bacteria, he was able to study their effect on the mycelium of the pathogen. Among those found to possess inhibitive powers was *Trichoderma lignorum*. In culture especially, hyphae of the pathogen were checked or killed by direct attack of *T. lignorum*. Bisby, James, and Timonin (4), when isolating and identifying fungi from Manitoba soils, found that *T. lignorum*, when inoculated into pots containing *Helminthosporium* and *Fusarium* spp., checked the pathogenic action of these latter and rendered them harmless. They offer the suggestion that *Trichoderma Koningi* and certain of the *Penicillia* may also inhibit pathogens. Weindling (95), as mentioned, found this true of *T. Koningi*. Allen and Haenseler (1) studied the action of *Trichoderma lignorum* on *Rhizoctonia* and *Pythium* which were responsible for seed decay and damping-off of cucumbers. Laboratory tests showed that *T. lignorum* was decidedly antagonistic to these pathogens. By inoculating the soil with *T. lignorum*, the authors found that *Rhizoctonia* and *Pythium* were considerably reduced. *Trichoderma*, in turn, may be inhibited by actinomycetes, the degree of antagonism depending upon various factors as shown by Waksman and Foster (99).

Following the hypothesis that continuous production of cotton on certain neutral to alkaline soils has brought about an unbalanced soil population in which *Phymatotrichum omnivorum* has become dominant, Thom and Morrow (90), experimenting with mould inoculation in cotton root-rot areas, found an absence, or only sporadic presence, of *Trichoderma* species and other moulds. A selected series of fungi, including *Trichoderma*, were inoculated into experimental plots of cotton and were subsequently recovered sufficiently consistently at the point of inoculation to justify further experiments toward such utilization of antagonism in control of detrimental species. Daines (17) and Christensen (14) also have shown recently that species of *Trichoderma* may exert antagonistic action against pathogenic fungi.

PROTOZOA

Hino (44) studied the action of protozoa as well as that of bacteria and fungi on various plant pathogens. Protozoa in the soil, under suitable soil temperatures, were found to prevent potatoes from being attacked by

B. aroideus. Such organisms as *P. Hyacinthi*, *P. Citri*, and to a lesser degree *Fusarium* and *Penicillium* spp. were also preyed upon by protozoa. Many common bacteria were also found to have an antagonistic action on *B. aroideus*. Chief among these were *B. prodigiosus*, *B. proteus*, *B. Megatherium*, and *B. lactis acidi*. Again, *B. solanacearum*, the causal organism of wilt of Solanaceae, was found to be killed by antagonistic action of *B. mycoides*, *P. fluorescens*, and *B. cereus*.

Though concerned with animal rather than plant pathogens, Rhines (77) studied the relation of soil protozoa to acid-fast bacteria, finding that the species of mycobacteria tested hindered the development of amoebae. It was suggested that their effect is due to toxic action, by acting as indigestible bodies, or by a combination of factors. Drechsler (18, 19, 21) found that various soil protozoa and nematodes were destroyed by certain Phycomycetes and Hyphomycetes. Though an extensive literature on soil protozoa has accumulated, our knowledge of the relationship of this group of organisms to plant pathogens is very meagre. Many studies have shown an influence of protozoa on saprophytic soil bacteria, an influence formerly considered detrimental. Later investigations, summarized by Cutler and Crump (16), have shown that protozoa may have a beneficial effect on certain processes carried out by bacteria, presumably by keeping the latter at a high state of physiological activity through constant reduction of numbers. The comparatively recent work of Koffman (56), however, ascribes to soil protozoa but an insignificant rôle in affecting the bacterial population of the soil and microbiological processes. Accordingly the importance of protozoa in soil, and in particular their possible direct or indirect effects on plant pathogens, are open questions.

MECHANISM OF ANTAGONISM

The inhibitory action of certain soil saprophytes has been shown in a number of cases to be a material factor in checking various plant pathogens. However, it is easier to demonstrate the results of saprophytic action on plant pathogens than it is to explain the actual mechanism that brings about this action. The outstanding difficulty encountered is that of emulating field conditions in the laboratory, though laboratory work is essential in order to study various by-products, toxins, enzymes, etc., which may be involved in antagonism. That it is easy to study the possible parasitizing and antagonistic effect of one organism upon another on a Petri plate has been proved by a large number of investigators, but it is another thing to study the action in the soil. As Broadfoot (7) has pointed out, the fact that one organism may be antagonistic toward another in culture, is no reason for assuming that the same action will take place in the soil.

There is no doubt, as Henry (39), Hino (44), Waksman (98) and others have pointed out, that there are a great many factors involved in producing manifestations of antagonism. Conditions such as temperature, oxygen supply, moisture content, reaction, soil structure, organic matter, and others may influence greatly any one or more groups of organisms in question. To combine all these factors to form a suitable condition necessary for one organism to parasitize another would be a difficult under-

taking, and for the most part the investigators have elected to keep these various factors in view, studying them from a general standpoint, and have confined their endeavors to determining the physiological mechanism or factor of inhibition and antagonism. In this regard, results have been varied and numerous theories advanced, some quite convincing, others less so. It is evident that much more work must be done before many cases of inhibition of plant pathogens by soil saprophytes can be definitely ascribed to any one or more factors. "Toxicity," "soil toxins", "repression", "exhaustion", "pH values", "lysis", "staling", "enzymes", "antibiosis", "metabolic products", "parasitism", "lethal principle", "starvation", "suppression", "biological control", and other factors are the basis of some of the theories advanced as to the cause of antagonism. Some of the main hypotheses, when supported by experimental data, may be considered.

Toxins

The idea that toxins are responsible for antagonism of different organisms is probably the most frequently advanced theory. Much of the work on this subject does not concern soil organisms and need not be reviewed here. Apart from the question of suppression of plant pathogenic organisms, various workers such as Greig-Smith (36), Hutchinson and Thaysen (47), Lewis (60) and others have demonstrated the production by soil organisms of certain toxic substances, though no definite conclusions can be arrived at as to whether such toxins can accumulate in sufficient amounts in soil to have a practical inhibiting effect. Smith (86) demonstrated a diffusible toxin, produced by *Botrytis cinerea*, and suggested that it may be oxalic acid by nature. Potter (73) detected a specific toxin produced by *P. destructans* which he suggests is a waste product.

Machacek (62), and Greaney and Machacek (35), in their studies of associative action involving plant pathogens, believed the inhibition of one organism by another to be due to toxic substances of undetermined nature. Weindling (94), studying the action of *Trichoderma* on soil fungi and later (95) in noting the effect of fungi parasitic on *R. Solani*, suggests that toxic substances are a factor in preventing growth. In another investigation the same author (96), studying *Trichoderma* parasitic on Rhizoctonia, finds a "lethal principle", and develops a "lethal index", the reciprocal of the minimum concentration at which *Rhizoctonia* is killed. He claims it is secreted into the surrounding medium by young hyphae only, and appears to be a single chemical product, neither enzymic nor autolytic. It rapidly decomposes, but is not destroyed by autoclaving. The efficiency of the lethal effect decreases with increasing pH. If charcoal is added, poor lethal effect is produced, thus confirming other investigations (47, 60). Weindling and Emerson (97) later isolated a crystalline constituent of the lethal principle produced by a culture of *Trichoderma*. It was found to be lethal to *Rhizoctonia* hyphae up to a dilution of 1–300,000. Tims (91) found a toxic principle produced by actinomycetes antagonistic to *Pythium* when grown in culture. Owing to the fact that filtrates were toxic to cultures of *Pythium* on plates, he suggests that a toxin is more probable than theories of exhaustion or starvation. He found that the toxic principle was partially destroyed by heat, though pH was not the

inhibiting factor. Allen and Haenseler (1) found much the same results. Working with *Trichoderma* spp. parasitic on *Rhizoctonia*, they demonstrated a principle or toxin which was decidedly lethal. Like Tims they showed that the filtrate was lethal, not only at full strength, but diluted to 40%. They inactivated the toxin by heating it 10 minutes at 100° C., and also destroyed its potency by bubbling oxygen for 5 minutes, or letting it stand for 20 days. The inhibitive action was produced by the toxin and the intermediate presence of the organism was not necessary. Brömmelhues (8) in experiments with *H. sativum* and *Penicillium* sp. antagonistic to *O. graminis* in culture, declares that the inhibitory action was owing to a toxic substance, thermostable, and diffusible in agar. It appears to depend upon the nitrogen source in the medium and is not owing to lack of nutrients or acid conditions.

Borodulina (5), studying the mutual relationships of actinomycetes and *B. mycoides*, suggests metabolic toxins as the cause of the depressing effect on *B. mycoides*. Unlike Tims (91) and Allen and Haenseler (1), he found that high heating did not inactivate the toxic properties, and like Weindling (96) found that increasing acidity considerably strengthened the toxic action, while alkaline conditions weakened it. The action on *B. mycoides* weakened its ammonifying power, and when strong, prevented spore formation, and also caused the production of pleomorphic and variant forms. The work of Leemann (59) is suggestive rather than conclusive. He tested such preparations as secretions and extracts of micro-organisms, as well as making observations of the interaction of different species in relation to such pathogens as *Helminthosporium sativum*. As a result of his observations he believes that micro-organisms, pathogenic or non-pathogenic, can supply us with substances useful as preventive measures against parasitic attack.

Much has been written on the nature of toxins and many ideas have been advanced. These analyses have been more or less confined to antagonism in culture of many species of organisms, and there are few references as to the nature of possible toxins responsible for the inhibition of plant pathogens. As mentioned before, what is toxic in culture may or may not be toxic in the soil. Such authors as Bewley (3) and Farrell (25) suggest that toxins are exo-enzymes; Lee (58) and Rosen (78) believe that the effect is due to nitrites. Lathrop (57) suggests aldehydes; Smith (86) and Haskell (38), and Kitagama and Kawamura (55) suggest organic acids. Holman (45) suggests that amino acids may form toxic products.

Lysis

Chudiakov (15) advances the theory of lytic action of soil bacteria on parasitic fungi. He found species of *Achromobacter* and *Pseudomonas*, capable of producing lysis of various *Fusaria* and other fungi and suggests that these may be widespread in the soil. Where they are lacking, as in flax-fatigued soils, *Fusaria* spp. are abundant. *Fusaria* introduced into soil containing active lytic bacteria will not develop. An interesting fact was discovered in the protection of wheat seedlings from attack when lytic bacteria were introduced simultaneously with *Fusaria* spp. Wheat is protected under these conditions, but if the bacteria are introduced 24 hours later, they are unable to protect wheat from *Fusaria*, sown 3 days

after. Novogrudskii (67) found that bacteria responsible for lysis of fungi were widespread in soil and on plants. Various fungi were grown in pure culture on potato agar plates. To these were added small amounts of soil, and lysis was determined by a dissolving of the fungi. Inoculations from the lysed spots gave pure cultures of the bacteria.

A related problem is that of the relation of bacteriophage to plant diseases. Not only from plants, but also from soil, various investigators have isolated bacteriophages active against a variety of plant pathogens. In most cases the lytic agents have been employed against bacterial pathogens though in some instances application has been made to actinomycetes. Since this subject has been recently reviewed by Katznelson (50) it need not be considered further here.

Enzymes

Certain investigators have been led to believe that enzymes are the cause of one organism antagonizing another. Bamberg (2) suggests that enzymes were produced by the bacteria responsible for the inhibition of *U. Zeae* and that these enzymes were able to destroy the sporidia of the pathogen in 10 to 14 days on culture. Confirming this, Johnson (48) working with certain bacteria antibiotic to various smut fungi, maintained that certain of them liberated enzymes which were able to dissolve the chemical constituents of the cell walls of the sporidia. Fawcett (27) states that the depressing of disease organisms is probably related to the combination of enzymes liberated and their resultant production of inhibiting substances. In 1932 Weindling (94) working with *T. lignorum*, suggests enzymes or toxins, but in 1934 (96) working with the same organism, affirms the non-enzymatic nature of the lethal principle found. Reid (76) discovered an inhibiting substance produced by a mould which was not common, but selective in action affecting several unrelated species of bacteria. Light, oxygen, hydrogen, and carbon dioxide prevented the production of the substance. He found that it was relatively thermostable and composed of the following enzymes: erypsin, catylase, lipase, and traces of amylase, trypsin, and amidase. Enzymes may also account for "secreted substances" of Sanborn (80) and the "metabolic products" of Broadfoot (7), Borodulina (5), and others.

Staling

Many authors have attempted to link up the effects of staling phenomena, demonstrated in the laboratory, as the definite cause of inhibition and antagonism, but this is difficult to prove in pot or field and is hard to separate from "toxic" effect. Pratt (74) working on the staling effects of fungal cultures, found that exhaustion was not important and that staling was not owing to an enzyme. She showed that bicarbonates were present in the staled product, and that these were responsible for the inhibition of *Botrytis* spores. The formation of bicarbonates resulted from addition of carbon dioxide to a basic radical of a nitrogenous product. Many of these toxic staling substances were capable of being adsorbed by charcoal. Brown (11) to a certain extent confirmed this; he maintains that a medium may become incapable of supporting growth, but that this stage is reached before the food is exhausted. The nature of staling varies,

not so much according to the type of organism, but more according to the form of nitrogen supplied in the medium. In the production of growth-inhibitory substances by fungi, the author also found the staling factor to be bicarbonates, which appear to have a much more repressive action than carbonates or hydroxides. He states that the staling of a culture accompanied by the accumulation of bicarbonates is inevitable if the nitrogenous food is such as to furnish a basic ion, the latter combining with carbon dioxide to form bicarbonates. Boyle (6) studying the physiology of parasitism, found that *Fusarium* sp. rendered a medium unfavorable for further growth, and attributed this fact to toxic staling products rather than to lack of nutrients. Moreover, he found that pH values of a staled medium did not appear to be a limiting factor. Brown (10) previously demonstrated the formation of thermostable, mutually inhibiting substances by *Helminthosporium sativum* and a bacterium. The latter organism and its products inhibited the growth of the pathogen, as well as of other members of the same genus.

Some interesting experiments were conducted by Carter (12) who studied the diffusible nature of an inhibitory agent produced by bacteria. The isolated organisms inhibited *Helminthosporium sativum* on potato dextrose plates at a distance of 10 to 15 millimeters. The staling effect of the agar on which the organisms were cultured was not destroyed by autoclaving. He showed that the products of staling diffuse into the fresh agar, and moreover, these products were capable of diffusing into water, producing "stale water" which also proved inhibitory to *H. sativum*. Sanford and Broadfoot (83), who showed such conclusive results in their experiments with *Ophiobolus graminis*, tentatively advanced the theory of the staling products of metabolism as the probable cause of inhibition. Vasudeva (93) in his studies on physiology of parasitism, showed that *Botrytis Allii* interfered with the vigour of parasitic attack by *Monilia fructigens*, and other organisms. He states that this reduced parasitism shown by mixed cultures can be explained on the basis of staling phenomena.

pH Values

The reaction of the soil, whether alkaline or acid, was at first thought to be a primary factor as to the cause of inhibition or antagonism. However, various workers (6, 7, 62, 83, 91) are prompted to the belief that in most cases pH values are not the limiting inhibitory factor. There seems to be little doubt that acid or alkaline conditions may enhance the results or in some cases lead to the production of the inhibitory factor. Some investigators, however, have shown that pH values are important and may be the sole cause of inhibition. Rosen and Shaw (79) demonstrated that when *S. Rolfsii* was grown with a *Fusarium* sp. on a medium below pH 6.9, the latter was completely outgrown by the former. The reverse was true if above pH 6.9. Borodulina (5) maintains that the antagonistic action of certain actinomycetes toward soil organisms is increased with increasing acidity, and weakened under alkaline conditions. Sanford (81) showed that acid-producing soil organisms depressed the growth of alkaline loving *A. scabies*. Most workers are of the opinion that in certain cases, pH values may be responsible for some antagonism in culture, but that they have no appreciable action in soil because of its strong buffer action.

Growth Factor, Rhizosphere

Sanford (82), in his review of some soil microbiological aspects of plant pathology, shows that such pathogens as *Helminthosporium sativum* and *Ophiobolus graminis* utilize soil nutrients and undecomposed organic matter, but just what nutrients are essential is not known. He points out that disease is usually reduced by summer-fallow, possibly on account of lack of food for the pathogen, or an adjustment of the general soil flora and fauna unfavourable to the parsite. Padwick (69) noted growth promoting factors present in plant or animal extracts necessary for the development of *Ophiobolus graminis* and found certain bacteria capable of replacing the growth factor in synthetic solutions. The author believes that such factors play an important part in maintaining the balance of micro-organisms in the soil. It is possible that summer-fallow may result in saprophytes keeping the growth factor at a low level in the soil and so holding the disease organisms in check. Padwick (68), in experiments with wild and cultivated plants, found that *O. graminis* was unable to spread on unplanted soils owing to saprophyte antagonism and to lack of growth factor. Recent work by Waksman and Hutchings (100) on mixtures of soil organisms attacking plant materials would indicate that the associative action of organisms play an important part in the liberation of extracts, and that one organism may influence another considerably in this regard. They show, for instance, that a strong cellulose-decomposing fungus such as *Trichoderma* was found to attack proteins of alfalfa plants in preference to cellulose. However, in the presence of another organism which could attack proteins also, but not cellulose, *Trichoderma* was forced to attack the complex carbohydrate. It is quite possible, therefore, that saprophytes in association with pathogens may, by inhibiting the so-called "growth factor", or by utilizing certain extracts necessary for the growth of pathogens, be responsible for the food exhaustion as suggested by various investigators (31, 39, 62, 64).

A closely related problem is that concerning the factors which modify the development of organisms about the roots of plants. In this zone, the rhizosphere, there is doubtless a mutual influencing of growing plant and soil micro-population which may well have an effect on plant pathogens. As far back as 1904 Hiltner (43) conceived the theory that bacteriorhiza formations may act in preventing penetration of roots by injurious organisms. Different workers, such as Truffaut and Vladykov (92) and Starkey (87), found larger numbers of soil organisms about the roots of plants than elsewhere. The following factors concerned with increased concentrations of micro-organisms in the rhizosphere may be mentioned: *(a)* the supplying of food for the activity of organisms by dead root cells, *(b)* the excretion of readily decomposable compounds by the roots, *(c)* the excretion of growth-promoting substances, *(d)* the excretion of carbon dioxide, and *(e)* adjustment of reactions by roots. Any one or a combination of these factors may be important in affecting the activity of plant pathogens. In this connection observations of such workers as Howard (46) and Jones (49) on the influence of soil environment on disease resistance may be mentioned.

Thom and Humfeld (89) noted increased numbers of micro-organisms in samples of soil taken in proximity to plant roots. Working with tobacco

root rot, it was found that greatly increased numbers were shown upon samples of roots known to be infected, or which had been grown in heavily infected soil. Fewer numbers were found on tobacco plants known to be resistant to root rot. Lipman and Starkey (61) maintain that it is in the rhizosphere that the soil plays its important rôles in nutrition of higher plants. It is here that symbiosis, stimulation, toxicity, and inhibition become impressed upon the plants.

It is evident that no one factor can be responsible for the various examples of antagonism. Different diseases appear to have their own association of organisms, while numerous other conditions have to be studied carefully before conclusive results on that one disease can be obtained. Toxins may be liberated by certain saprophytes as regards one disease, and enzymes liberated by others; pH values may be the controlling factor in one case, and reduction of growth factor in another. Actual proof for some of these theories is lacking, and according to Sanford (82), not only will a great deal more work have to be done, but better and more conclusive results will be obtained only when it is possible to emulate field conditions in the laboratory. That workers are realizing this is borne out by the fact that more and more work is being conducted in pots and greenhouse where it is possible to observe the actual advantages or disadvantages of mixtures of micro-organisms on plant growth. According to Lipman and Starkey (61), "There is opened a new field of study and perhaps of application. Only as the influences of various organisms on one another are understood and the extent of the operation of their effects in soils is known, can there be any real appreciation of the associative developments of micro-organisms in such a complex environment as the soil".

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THE EFFECT OF BORON ON THE RESPIRATORY BEHAVIOUR OF TOMATOES[1]

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Boron has proven to be an important minor element in the nutritional diet of plants. Heretofore no attempt has been made to study its effect on the repiratory metabolism of growing or storage tissues.

Thirty plants of Bonny Best variety were selected for the production of the fruits used in the experiment. These plants were potted in sterile sand after removal from the seed bed on July 7th, 1937. At this time the plants were about 4 inches to 5 inches high.

The feeding of these plants were carried out in the greenhouse by the administration of nutrient solutions. These plants were divided into three series according to boron treatment. Series A received a moderate amount, Series B received a very small amount while C was fed boron to excess.

The stock solutions were made up as follows:

$MgSO_4 . 7H_2O$	—	140 gms.	—	2000 cc. H_2O
KH_2PO_4	—	70 gms.	—	2000 cc. H_2O
$CaCl_2$	—	150 gms.	—	2000 cc. H_2O
KNO_3	—	50 gms.	—	1000 cc. H_2O
NH_4NO_3	—	360 gms.	—	4000 cc. H_2O
$MnSO_4 . 2H_2O$	—	1.23 gms.	—	2000 cc. H_2O
$FeCl_3 . 6H_2O$	—	20 gms.	—	1000 cc. H_2O
H_3BO_3	—	1 gms.	—	1000 cc. H_2O

The method of administering the nutrient solutions was carried out by applying 200 cc. of solution three times a week to each plant. This solution was made up as follows:

Amounts of stock solutions in 2000 cc. of water:

$MgSO_4 . 7H_2O$	—	28 cc. of stock solution
KH_2PO_4	—	31 cc. of stock solution
$CaCl_2$	—	29.6 cc. of stock solution
KNO_3	—	32 cc. of stock solution
NH_4NO_3	—	32.8 cc. of stock solution
$MnSO_4 . 2H_2O$	—	2.1 cc. of stock solution
$FeCl_3 . 6H_2O$	—	10 cc. of stock solution
Series A		
H_3BO_3	—	11.2 cc. of stock solution
Series B		
H_4BO_3	—	0.11 cc. of stock solution
Series C		
H_3BO_3	—	65.0 cc. of stock solution

[1] Contribution No. 515A from the Division of Horticulture, Dominion Experimental Farms System, Ottawa, Ontario.

[2] Division of Horticulture.

Unfortunately the experimental material was moved into an unshaded greenhouse while the fruit on the first truss were still quite green and small. This resulted in a serious set back in growth as well as the development of considerable blossom-end rot. In spite of this fact some healthy-appearing fruit of similar age (50 to 55 days after fruit set) was obtained. One fruit of each series was selected from these and the respiratory behaviour at 55° F. studied.

In order to obtain measurements of CO_2 output the tomatoes were placed in individual gas-tight chambers immersed in a constant temperature bath. A CO_2 free air stream passed over the fruit in the chamber and the CO_2 evolved was collected by absorption in BaOH in Pettenkoffer tubes. Measurements were made by titrating the contents of each tube every 24 hours. The resulting rates expressed in mgms. of CO_2 per Kgm. of fruit are shown in Figure 1.

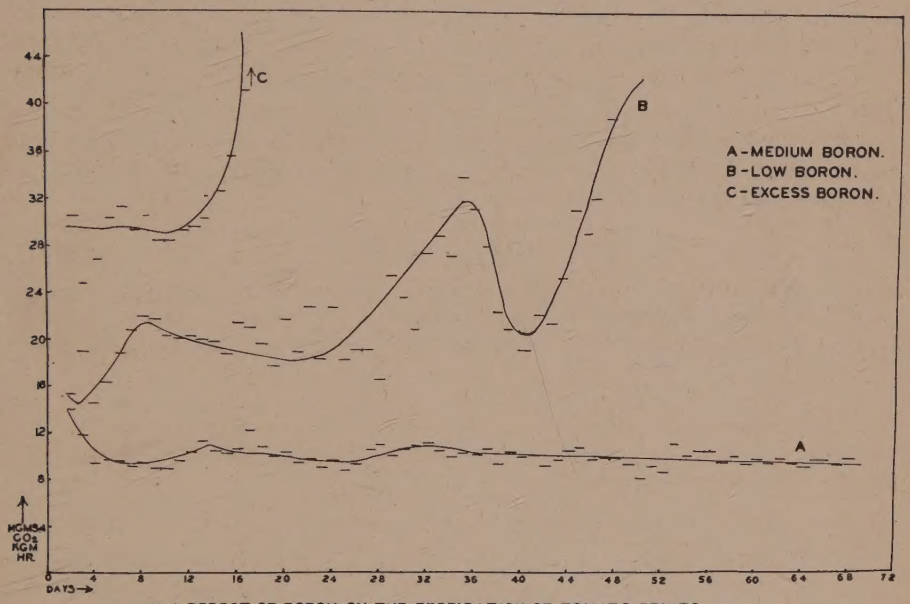

FIG 1 EFFECT OF BORON ON THE RESPIRATION OF TOMATO FRUITS.

The fruits in series A and B were yellow green with A being slightly more advanced than B. The fruit from series C was very slightly orange being considerably more advanced than either A or B.

On account of the accident in growing of the plants and the subsequent lack of material it was at first deemed inadvisable to attempt any theoretical formulations. Nevertheless so great a divergence occurred in the resulting respiratory curves of the tomatoes from the various feeding treatments that a brief survey of their form may be of interest.

Blackman and Parija (1) have shown that apples are of three types as classified by the form of their respiratory drift. The longest keeping types were those of delayed and lower climacteric. Walford (2) found that good keep in tomatoes was associated with a steady respiratory behaviour as determined in his late fall and winter grown tomatoes.

In Figure 1 it will readily be seen that the respiratory curves represented are distinctly different from each other. Curve C, representing a fruit from a plant fed boron to excess, is much higher at the outset. Unfortunately the curve was influenced severely by breakdown at about the sixteenth day. Within this relatively short period there is no indication of the lowest point being as low in CO_2 output as any point in either of the other curves.

Curves A and B commence at approximately the same rate but after several days two distinctly different trends are assumed. Curve B shows extreme fluctuations and evidence of a double senescent hump. This curve assumes an abnormal ascent at about day 44 resulting from the onset of breakdown.

Curve A represents the drift of CO_2 output from a fruit grown on a plant receiving normal amounts of boron. This curve is characterized by low steady rates of carbon dioxide output with the absence of any distinct hump or climacteric. Fruit C was further advanced in colour than B at the outset but remained in good condition for a much longer period.

The effect of boron might be assumed to produce a steadying effect on CO_2 output. If given to excess the rates appear to be steadier than if boron is lacking but assume a higher level. If boron is administered in proper amount a low steady rate is produced which appears to be conducive to better keeping properties.

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AUTHOR INDEX

ARTICLE FRANCAIS

ERRATUM

In the December 1937 issue, Volume XVIII, No. 4, the illustration over the caption for Figure 19, page 192, belongs to Figure 20, page 195, and the illustration over the caption for Figure 20 belongs to the caption for Figure 19.